REPORT

of

COMMITTEE ON THESIS

THE undersigned, acting as a committee of the Graduate School, have read the accompanying thesis submitted by Ross A. Thuma for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science

F. F. Alway
Chairman

R. M. W.

C. O. Rosendahl

.... 191

POT EXPERIMENTS VERSUS CHEMICAL ANALYSIS AS AN INDICATION OF THE RESPONSE OF THE SOILS TO FERTIL- IZERS.

By R. A. Thuma

A THESIS

Presented to the Graduate School of the University of Minnesota in partial fulfilment of the requirements

For the Degree of Master of Science

St. Paul, Minnesota, April 15, 1915.

CONTENTS.

PHOTOGRAPHS

TABLES.


8774

GENERAL VIEW OF THE GREENHOUSE, CROP OF 1912-13.

POT EXPERIMENTATION VERSUS CHEMICAL ANALYSIS AS AN INDICATOR OF THE RESPONSE OF SOILS TO FERTILIZERS.

INTRODUCTION.

The present study is based upon data secured during the years 1912, 1913 and 1914 in the soils laboratory and in the plant houses of the Great Northern Railway at St. Paul. As early as 1908 this company was contributing to the support of some twenty-five demonstration farms in Montana which were conducted under the direction of the Montana Agricultural Experiment Station. While this station secured many valuable experimental data the purpose of the farms was to demonstrate that by the use of a clean summer-fallow good crops of grain could be produced every alternate year at a profit on part of those lands in Montana, which, up to that time, had generally been considered fit for only pastoral purposes.

POT EXPERIMENTATION VERSUS CHEMICAL ANALYSIS AS AN INDICATOR OF THE RESPONSE OF SOILS TO FERTILIZERS.

INTRODUCTION.

The present study is based upon data secured during the years 1912, 1913 and 1914 in the soils laboratory and in the plant houses of the Great Northern Railway at St. Paul. As early as 1908 this company was contributing to the support of some twenty-five demonstration farms in Montana which were conducted under the direction of the Montana Agricultural Experiment Station. While this station secured many valuable experimental data the purpose of the farms was to demonstrate that by the use of a clean summer-fallow good crops of grain could be produced every alternate year at a profit on part of those lands in Montana, which, up to that time, had generally been considered fit for only pastoral purposes.

These demonstration farms proved a great success, but later the management of the railway decided that a greater diffusion of knowledge among the settlers could be secured by replacing the demonstration farms by a very much larger number of smaller areas, so-called demonstration fields. These were carried on by the railway independently, the work being placed in charge of Professor Thomas Shaw,[a] late Professor of Animal Husbandry at the University of Minnesota. This permitted the work to be carried out in all the other states in which the lines of the railway passed through dry-farming lands as well as in Montana. This also proving a success an additional line of work was undertaken in 1912. The latter was intended not for the new settlers of the semi-arid regions who were to be shown how, by methods of proper tillage and cropping, they could make a success of farming their virgin soils,

[a] T. Shaw, Dry Farming - The Pioneer Co. - 1911.

but for the farmers in the older settled districts in North Dakota and Minnesota, who, while doing very well, were not obtaining yields of grain that were considered really creditable.

"The farmers of Germany, Denmark, France, England and other European countries, have made use of the discoveries of Liebig of Germany and Lawes and Gilbert of England, and as a result they are averaging over 30 bushels of wheat per acre on land that originally was not so good as ours. While these foreign countries are developing under economic conditions different from ours, yet, the American farmer can well make use of the basic agricultural principals upon which their agriculture has been builded."

While on the dry land the farmer had to be shown the importance as well as the best means of increasing the moisture supply, a question of tillage only, in Minnesota and North Dakota he was to be shown how his crop yields might be increased, both by improving the tillage and by increasing the supply of nutrients for the crop plants. It was assumed that if the farmer saw, produced in fields on his own land, crops much superior to those secured upon the rest of his farm he would not

a. F.R.Crane, Better Farming for the Northwest, P.1-1913.

be content with his present yields, but would endeavor to increase them by every means that seemed to assure a profit, whether by an increase in the amount of his live stock, by an increase in the acreage devoted to leguminous crops or by the use of commercial fertilizers.

This new line of work was placed in charge of Professor F. R. Crane, who, in the spring of 1912, organized a corps of field workers to care for the demonstration plots on each of 151 selected farms in Minnesota and North Dakota.

"Each tract was supplied, as nearly as could be ascertained with the elements of fertility required to enable it to grow a good crop. Only tested seed was used, and the gound was cultivated properly."[b].

As fertilizer experiments on any considerable scale had not yet been inaugurated by the University of Minnesota or by the North Dakota Experiment Station it was decided to install a chemical laboratory for the analysis of samples of soil from demonstration fields

b. F.R.Crane, Better Farming for the Northwest, p.2.

and to utilize the extensive private greenhouses of Mr. J. J. Hill for pot experiments with different fertilizers. There were secured, during the autumn of 1912, samples of soil for chemical analysis and for pot expermiments from each of the five-acre tracts to be used for demonstration purposes during the season of 1913. Mr. J. O. Nore was placed in charge of the work started in the laboratory and the plant houses in the autumn of 1912, being joined by the writer at the first of December. The former removed to the University of Wisconsin at the end of March, 1913, since which time the latter has been in full charge of the work. As he has had nothing to do with the demonstration plots the data from these[a] are not dealt with in the present study.

During the summer of 1913 the writer began a comparison of the fertilizer needs of the different

a. F.R.Crane, Better Farming for the Northwest, G. N. Railway, St. Paul, 1913.
. F.R.Crane, How to Make the Farm Pay, G. N. Railway, St. Paul, 1915.

soils as indicated by the pot experiments, with those that might be inferred from the chemical analyses. Later, at the suggestion of Professor Crane, he consulted Professor Alway for assistance and arranged to have a critical analysis of the data of the two season's work presented as a thesis for the Master's degree. The question to be answered by the study of the data was not whether it is possible, by means of chemical analysis, by pot experiments, or by the two together, to predict the response to different fertilizers applied to the same soils under field conditions but _to what extent is the response indicated by pot experiments on any particular soil or collection of soils in accord with that indicated by the chemical analyses._ Further it should be emphasized that neither the analytical nor the plant-house work was started with the purpose in view of securing data for the present study. Circumstances, however, having made these data available, they have been subjected to a critical analysis. Many changes in the method of procedure would have been desirable if the work had been planned to form a basis for this study, but under the circumstances every other consideration had to give way to rapidity of execution. Thus, in order to permit 205 surface soils and a corresponding number of subsoils to be analyzed, and the same number to be subjected to pot tests and a report to be prepared on the work within the space of six months, it was necessary to omit many niceties of procedure, especially in regard to the pot work.

The writer assumes the entire responsibility for the accuracy of the chemical analyses and the reliability of the other data reported. For assistance in laboratory and greenhouse work he acknowledges the work of W. E. Kruger and H. L. Newcomb, and wishes to express his indebtedness to Prof. F. R. Crane for his assistance and to Prof. F. J. Alway for helpful suggestions in the analysis of the data.

HISTORICAL.

A careful search through the literature of the last twenty years reveals the fact that there are almost no data extant which bear upon the problem in question. It must be understood definitely that the problem is the relation between the chemical analysis of the soil and its response to fertilizers as indicated by pot cultures. There is a considerable amount of literature bearing on the response of soils to fertilizers in field tests, but they are not necessarily germain to the subject. Lyon of the Cornell Agricultural Experiment Station, Hopkins of the Illinois Station, Whitson of the Wisconsin Station and Kastle and Shedd of the Kentucky Station have all investigated the subject in question, but as yet none of them have published the results of their experiments.

The only paper which I have found bearing directly upon the subject matters of this thesis is a short note by Professor Fraps of the work in progress at the Texas Agricultural Experiment Station.

His method[1] of the determination of Phosphorus differs from that employed in this work in that he estimated only that portion of the phosphoric acid which was soluble in N/5 Nitric Acid, while the analysis on which this Thesis is based were those of total phosphoric acid. However, it seems probable that there is a more or less constant relationship between the total phosphoric acid content of the soil and that portion soluble in N/5 nitric acid, so that the results are roughly comparable. The determination of nitrogen was the same in both instances.

In brief the results are as follows:

1. "The average of a large number of pot experiments at the Texas Experiment Station shows that the active phosphoric acid, the active potash and the total nitrogen are directly related to the soil deficiencies

[1] Fraps, G.S. The Relation of Chemical Composition to Soil Fertility. Journal of the American Society of Agronomy, VII 33-36 1915.

brought out by the plants' growth."

2. "This method (pot culture) is the best one we have at present for studying the relative deficiencies of soil by chemical methods and should serve as a basis for further work from which to draw more definite conclusions."

THE DATA AVAILABLE AND THE SCOPE OF THE INVESTIGATION.

In the winter of 1912-13 soils from over one hundred plots were analyzed, determinations of total nitrogen and total phosphorus being made. Each soil was subjected to a pot test, using either oats, barley or wheat.

(Photo No. I.) Each set consisted of six pots, viz:

1. Blank	No fertilizer.
2. N.	Sodium nitrate.
3. P.	Acid phosphate.
4. K.	Potassium sulphate.
5. N.P.K.	Sodium nitrate, acid phosphate and potassium sulphate.
6. N.P.	Sodium nitrate and acid phosphate.

Unfortunately in the case of many of the sets the crops were scorched while drying so that only 100 sets remained complete at the time the crop was harvested. In such a study the chemical data on a soil are of value only when the pot experiments with it have been success-


BLANK
113
N
113
P
113
K
113
NPK
113
NP
113

Photo No. 1 - A POT CULTURE SHOWING THE EARLY
GROWTH OF THE PLANTS, 1912-1913

fully completed. So, the data on only 100 soils are available. For the first year's work, as the plants were not allowed to head out, they having been harvested at the stage of growth shown in Photo No. 2, there are data for only the total dry matter, there being none for either the grain or the straw alone. Barley was used on part of the soils, oats on others, and wheat on the remainder.

250 soils were analyzed in the season of 1913-14. Pot experiments with barley only, using the same fertilizers as in the previous year, were carried out successfully on these until the grain headed, but at that stage many of the plants in one out of the three rooms of the plant-house were seriously injured by fumes while treating them for insect pests. These were discarded while the plants on the remaining 189 sets were allowed to mature; for the latter the yields reported in Table III. refer to the combined weight of grain and straw. The grain was separated and weighed in


765
765
P
K
765

Photo No. 2 - A POTCULTURE SHOWING THE SIZE OF PLANTS
WHEN THE CROP WAS HARVESTED IN THE CASE
OF THE WORK OF 1912-13.

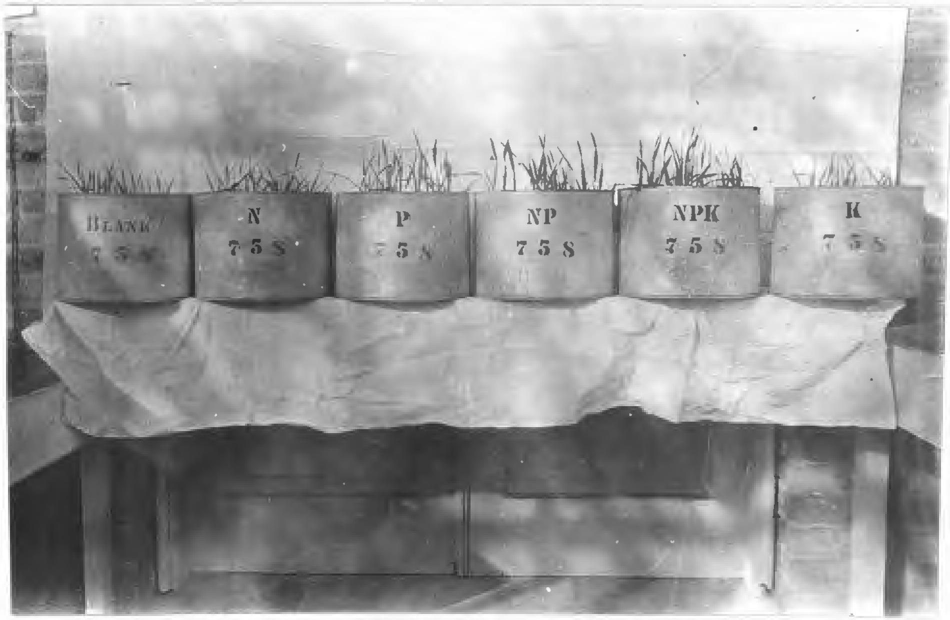
the case of only 24 sets. (Table V.) The extremely time-consuming character of this work prevented this separation being applied to the remaining sets. For 1913-14 there are data also on the number of tillers and the date of ripening.

THE COLLECTION AND PREPARATION OF THE SAMPLES OF SOIL.

Three separate samples of soil were secured by the field agents and sent to the laboratory. The one was for pot culture work and the other two for chemical analysis. For the former a representative sample of 150 pounds was taken from the surface 8 inches. Two samples for chemical analysis were taken with an auger $1\frac{1}{4}$ inches in diameter, viz: the surface soil, to a depth of 8 inches, and the subsoil from the ninth to the twenty-fourth inch. The smaller samples were placed in small sacks provided for this purpose, while the large sample was shipped in grain sacks. The latter on its arrival at the laboratory was emptied out upon a clean cement floor where it was well mixed, stones and rubbish being removed. It was then weighed out, 25 pounds of dry soil being placed in each of six pots. The pots, made of the best quality galvanized iron, were 9 inches in height and 12 inches in diameter, strengthened at the top by a heavy iron band to render them strong and durable.

THE FERTILIZERS USED.

The fertilizers applied to the pots consisted of 3 grams of sodium nitrate for nitrogen, 4 grams acid sodium phosphate for phosphorus and 3 grams potassium sulphate for potassium, these quantities being employed both alone and when two or all three were applied to one pot. For convenience the order of arrangement and marking in the greenhouse was from left to right, Pot No. 1 being marked B (untreated), Pot No. 2 N, (treated with nitrate), Pot No. 3 P, (treated with phosphate), Pot No. 4 N.P. (treated with both nitrate and phosphate), Pot No. 5 NPK (treated with nitrate, phosphate and potassium salt) and Pot No. 6 K (treated with potassium


BLANK 758
N 758
P 758
NP 758
NPK 758
K 758


BLANK 757
N 757
P 757
NP 757
NPK 757
K 757


BLANK 759
N 759
P
NP 759
NPK 759
K 759

Photo No. 3 - THREE SETS OF POT CULTURES SHOWING
THE GAIN IN EARLY GROWTH DUE TO
THE USE OF ACID PHOSPHATE.


BLANK
581
N
581
P
581
K
581
NPK
581
NP
581

Photo No. 4 - A POT CULTURE SHOWING THE EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZERS ON MINNESOTA SOILS.

sulphate only).

THE CROP AND ITS CARE.

Barley, oats and spring wheat were used in the first year's work while barley only was used the following year. The seed used was of the best quality and especially uniform. The soils were well watered, and then as soon as they were dry enough to work from 30 to 35 seeds were planted in each pot and covered with about half an inch of soil. All of the pots were planted on the same day. The number of plants was reduced to 20 when they reached a height of about two inches and the fertilizers added at this time. From the time the seeds were planted until the plants were 4 inches high each pot received 1 liter of water a week, while they grew from 4 to 12 inches 2 liters a week, and after this 3 liters a week until they commenced to ripen, after which the amount of water applied was gradually decreased. As the pots were water-tight the wide variation in the water holding capacity of the soils made it very difficult to keep all the plants properly watered.

All the data from the work of the first year, 1912-13, are reported in Table I., being arranged so as to permit comparisons of the relations of the response to different fertilizers with the chemical composition. The 100 soils were arranged first in the order of the nitrogen content of the surface soil, shown in the third column, and then in the order of the phosphorus content of the same, shown in the fourth column. On the basis of the nitrogen content the 100 are divided into three groups, the first, "high in N", including 33 soils, the nitrogen content of each of which lies between 0.530 and 0.365, the second, "intermediate in N", including 34 soils, each with a nitrogen content between 0.365 and 0.291, and a third "low in N", including 33 soils, each with a nitrogen content between 0.291 and 0.070 per cent. Each of these three groups has been subdivided into three divisions on the basis of the phosphorus content of the surface soil, those ranking from 1 to 33 on this basis being "high in P" (.071 to .047 per cent). Thus if a soil ranks 26 on the basis of its nitrogen content and 73 on that of its phosphorus the data on this soil will be found in the sub-division "high in N but low in P". A summary (Table II) permits of the direct comparison of the average results both by divisions and by groups. In the case of the latter the averages reported are weighted averages and not simply the mean of the three data from the three divisions of the group. Thus in the group "low in N" in the case of the yields on the pots which received a K fertilizer the 4 soils with "low N and high P" gave an average yield of 3.2 grams, the 11 soils with "low N and intermediate P" gave an average yield of 8.1 grams and the 18 soils with "low N and low P" an average yield of 8.5 grams. The mean of the three is 6.6 grams while the true or weighted average for the 33 soils is 7.7 grams.

The importance of the data in this table, aside from the support they lend to the conclusions drawn from the data in Table III lies chiefly in the unqualified support given the view that in pot experiments the plants should be allowed to reach maturity. The extreme opposite view has been advanced by the U. S. Bureau of Soils which allowed plants to grow only a few weeks, aqueous extracts of the soils being thus tested.

In Table III are similarly arranged all the data on 189 soils used in the second year, the "high, intermediate and low N" groups including 64, 63 and 62 soils, respectively. Table IV gives a summary of the data in the preceding.

The moisture content of the straw at the time the yields were determined is shown for 36 pots in the table below. It was practically the same in each. Thus, the comparison of the crop yields on the air-dry basis in such a study as this leads to the same conclusion as though the water content had been determined in each case.

Photo No. 5 - THE APPEARANCE OF THE GREENHOUSE
AT HARVEST TIME, CROPS OF 1913-14.

Moisture in air-dry straw when the crops were weighed.

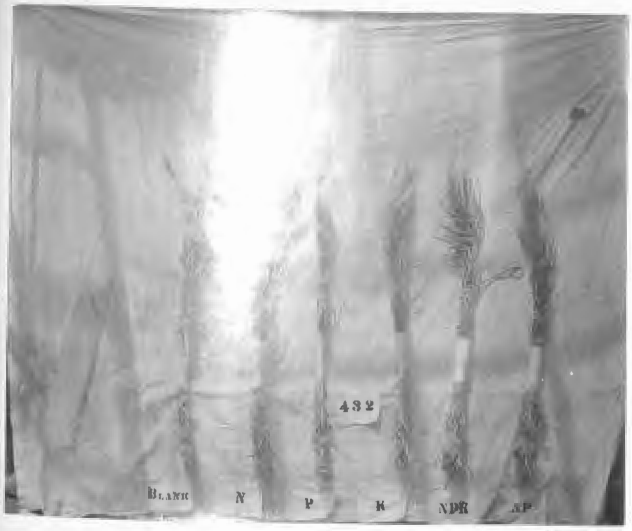
Soil No.	0 p.ct.	N p.ct.	P p.ct.	K p.ct.	NP p.ct.	NPK p.ct.
449	11.7	10.2	10.5	10.6	11.3	10.0
436	10.2	9.5	9.	10.	9.8	10.0
535	9.8	11.3	11.7	9.1	9.0	8.6
435	11.7	11.3	12.1	10.7	9.2	11.7
508	12.2	10.9	10.2	8.9	11.6	11.1
536	10.7	11.5	11.2	11.4	11.9	11.2
Ave.	11.1	10.8	10.8	10.1	10.5	10.4

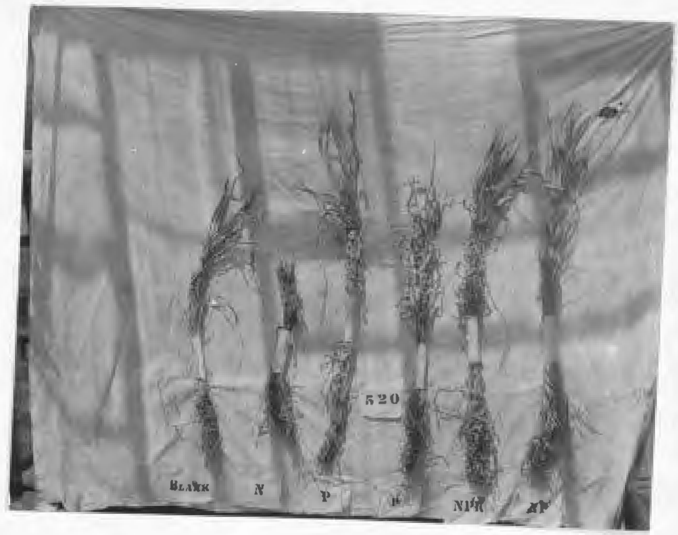
Average for all fertilized plots 10.5, for unfertilized 11.1 per cent.

The appearance of the green-houses when the barley headed is shown by Photo No. 5, while No. 6 shows a set of six as the plants were ripening. The condition and appearance of the crops at the time the yield of dry matter was determined is shown by the five

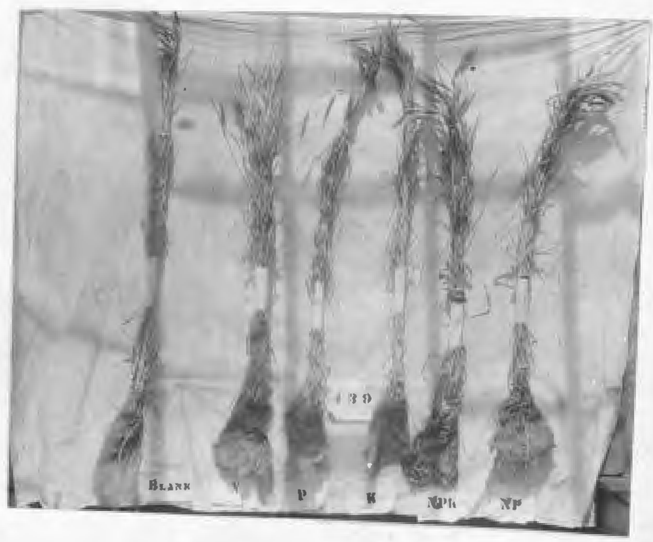

BLANK
435
N
435
P
435
K
435
NPK
435
NP
435

Photo No. 6.- A SET OF SIX POTS AS THE PLANTS WERE RIPENING.


432
BLANK
N
P
K
NPK
NP


520
BLANK
N
P
K
NPK
NP


BLANK
P
K
NPK
NP


BLANK
P
K
NPK
NP

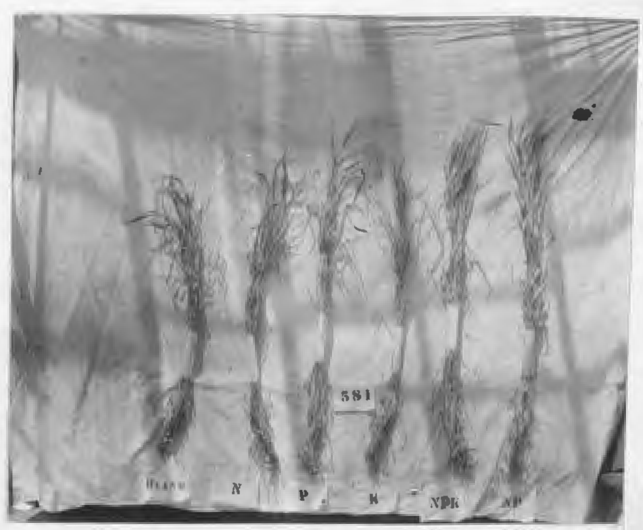

581
BLANK
N
P
K
NPK

Photo No. 7 - FIVE SETS SHOWING THE CONDITION OF
THE CROP AND THE WAY IN WHICH THE
CROP WAS HANDLED IN 1914.

sets in Photo No. 7.

Photos Nos. 8, 9, 10 and 11 show the grain from the 24 pots with four soils. These may be considered as strictly typical.

In table V. there are shown the yields of both grain and straw, the soils being arranged in the order of both the N content and the P content.

In the case of all 189 sets the number of tillers on each pot was counted between February 20th and March 25th, all those of any one set being counted on the same day. In the case of 40 sets a record was kept of the order of ripening and the different pots ranked. Thus, for example, in one set,(No. 512), the order of ripening and the consequent rank was as follows:
1. Untreated pot, 2 N - fertilized, 3 K - fertilized, 4 NP - fertilized, 5 P - fertilized, 6 NPK - fertilized. In Table VI. the data on this are given as well as the average height of the plants at maturity, and the final number of tillers. The tillers that died previous to

TABLE I. DATA ON THE WORK FOR THE YEAR 1912-13.

SOILS HIGH IN BOTH NITROGEN AND PHOSPHORUS

Soil No.	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
105	Rothsay, M.	1	11	.529	.224	.089	.072
17	Grand Forks, N.D.	2	3	.460	.211	.113	.088
70	Stephen, M.	3	32	.457	.248	.081	.077
26	Grafton, N.D.	4	8	.457	.146	.094	.064
40	Hamden, N. D.	5	23	.438	.181	.084	.070
32	Hansboro, N.D.	6	16	.432	.156	.086	.061
35	St.Thomas, N.D.	7	15	.432	.156	.086	.061
29	Hallock, M.	8	1	.425	.209	.178	.147
25	Minto, N. D.	9	6	.424	.274	.096	.083
104	Rothsay, M.	11	17	.421	.079	.086	.058
62	Brandon, N.D.	12	5	.419	.150	.099	.054
94	Barnsville, M.	14	13	.407	.138	.087	.071
36	Starkweather.	15	25	.403	.170	.084	.081
38	Webster, N. D.	16	10	.402	.195	.089	.073
101	Dalton, M.	17	18	.397	.195	.086	.064
15	Larimore, N.D.	18	33	.396	.186	.081	.056
86	Climax, M.	20	9	.393	.220	.093	.071
19	Aneta, N. D.	23	27	.388	.171	.083	.065
A	Dalton, M.	24	19	.387	.187	.086	.070
88	Humboldt, M.	27	4	.379	.153	.103	.077
61	Garfield, M.	28	24	.378	.159	.084	.055
50	Towner, N. D.	33	12	.366	.125	.088	.067
	AVERAGE	14	15	.418	.179	.093	.072

Arranged to show the relation of the yield
to the composition of the soil.

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Crop	Soil No.
5.5	5.5	10	15	15.5	5	W	105
3.2	3.7	3.9	4.1	4.1	4	B	17
5.3	6	10	16.2	18	6.8	B	70
8	12.9	12.5	17.4	16.2	10.5	B	26
7.3	7.4	10.5	13.5	14.9	8.5	W	40
12.4	15.5	31	28.5	27.8	15.9	W	32
12.4	15.5	21	28.5	27.8	15.7	W	35
17.3	19.5	26.5	29	29.5	17	O	89
5	7.8	5.8	15.5	10.5	6	B	25
5.4	8	9.3	13.2	10	5.7	B	104
3.5	4.7	5	6.1	5.4	4.9	W	62
24.8	28.5	24.4	43.5	42.2	28.7	O	94
8.2	13.2	19.5	19.2	28.2	10	B	36
14.5	17.4	14.8	19.5	19.2	18.4	B	38
8.2	9.7	12	8.8	8.4	7.6	W	101
2.5	2.5	2.9	2.7	3.1	2.7	W	15
6.8	7.2	8.8	10.2	9.8	6.6	B	86
3.8	4.6	5.8	5.5	5.5	3.7	O	19
7.5	7.3	12.5	18.5	19.6	12.5	B	A
19.2	23.3	20.2	25.5	23.5	17.2	W	88
6.6	7.3	7	7.8	7.8	7.6	W	61
5.1	6.5	6.8	7.3	6.9	5.8	O	50
8.8	10.6	12.8	16.2	16.1	10.		

TABLE 1. (Continued)

SOILS HIGH IN NITROGEN AND INTERMEDIATE IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.Ct.	Nitrogen in Sub-Soil P.Ct.	Phosphorus in Soil P.Ct.	Phosphorus in Sub-Soil P.Ct.
11	Sharon, N.D.	13	49	.417	.149	.077	.056
68	Argyle, M.	19	39	.393	.208	.079	.068
90	Tintah, N.D.	21	42	.391	.257	.079	.063
33	Hannah, N.D.	29	51	.377	.155	.077	.059
58	Morris, M.	32	52	.371	.205	.077	.083
98	Clara City,	10	54	.424	.198	.076	.071
13	Luverne, N.D.	25	38	.385	.215	.079	.062
	AVERAGE	21	46	.394	.198	.078	.066

SOILS HIGH IN NITROGEN BUT LOW IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.Ct.	Nitrogen in Sub-Soil P.Ct.	Phosphorus in Soil P.Ct.	Phosphorus in Sub-Soil P.Ct.
1	Lawton, N.D.	22	70	.397	.191	.070	.060
2	Melrose	26	73	.382	.176	.070	.057
3	Hamilton, N.D.	30	78	.377	.204	.069	.079
4	Bathgate, N.D.	31	87	.376	.147	.065	.067
	AVERAGE	27	77	.383	.180	.069	.066

SOILS INTERMEDIATE IN NITROGEN AND HIGH IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.Ct.	Nitrogen in Sub-Soil P.Ct.	Phosphorus in Soil P.Ct.	Phosphorus in Sub-Soil P.Ct.
1	Mayville, N.D.	36	21	.360	.200	.086	.061
2	Flay, N.D.	38	30	.358	.119	.082	.059
3	Minto, N.D.	41	14	.355	.200	.087	.079
4	Fosston, M.	44	29	.347	.133	.083	.062
5	Ayr, N.D.	45	7	.346	.139	.095	.077
6	St. Vincent, M.	46	26	.345	.138	.083	.067
7	Cando, N.D.	47	31	.344	.178	.082	.087
	AVERAGE	42	23	.351	.158	.085	.070

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Crop	Soil No.
5.6	5.4	6.6	7.5	8.9	6.3	B	11
8.3	7.7	10.2	12.8	12.4	11	B	68
5.9	11.9	8	8.3	21.5	8.2	B	90
13.8	14	16	22.2	32	9.2	W	33
3.5	4.2	4.7	4.5	4.9	4.3	O	58
3.8	4.2	3.9	4.5	3.9	3.4	W	98
10	12.2	15.5	22.8	20.5	13.8	W	13
7.3	8.5	9.3	11.8	14.9	8.0		
4.1	4.5	5.5	6.9	5.8	5.3		
9.8	11.	13.5	16.2	16.7	13.		
5.	5.5	5.5	6.5	6.5	4.7		
5.8	6.8	7.6	9.8	8.6	5.6		
6.2	6.9	8.0	9.9	9.4	7.1		
5.9	6.7	6.7	8.7	9.1	7.3		
27.5	33.	32.5	51.	46.	29.8		
12.	12.2	15.	19.4	17.2	10.2		
1.8	2.3	2.5	3.5	2.3	1.7		
3.	3.9	3.5	5.5	5.2	3.3		
4.5	5.7	5.2	6.5	9.1	5.5		
3.5	4.7	5.7	6.5	6.3	6.2		
8.3	9.8	10.2	14.4	13.6	9.1		

TABLE 1. (Continued)

SOILS INTERMEDIATE IN BOTH NITROGEN AND PHOSPHORUS.

Soil No	Locality	Rank in order of N.	Rank in order of P.	Nitrogen in Soil P.ct.	Nitrogen in Sub-soil P.ct.	Phosphorus in Soil P.ct.	Phosphorus in Subsoil P.ct.
1	Clara City, M.	37	36	.359	.151	.080	.064
2	Rutland, N.D.	39	58	.358	.224	.075	.065
3	Orr, N.D.	42	34	.351	.160	.081	.066
4	Hope, N.D.	48	40	.337	.146	.079	.065
5	Warren, M.	50	64	.334	.088	.071	.055
6	Benson, M.	51	37	.327	.211	.080	.074
7	Park River, N.D.	53	53	.324	.171	.086	.066
8	Bagley, M.	54	50	.323	.199	.077	.059
9	Tintah, N.D.	56	43	.318	.257	.079	.058
10	Lester Prairie	57	44	.318	.111	.079	.058
11	Tolna, N.D.	58	65	.315	.219	.071	.075
12	Warren, Minn.	62	35	.306	.088	.080	.058
13	Mentor, M.	63	48	.304	.144	.078	.060
14	Mayville, N.D.	64	45	.303	.166	.078	.059
15	Grove City, M.	66	66	.293	.118	.071	.057
16	Hatton, N.D.	67	57	.292	.139	.075	.080
	AVERAGE	54	48	.323	.162	.077	.064

SOILS INTERMEDIATE IN NITROGEN AND LOW IN PHOSPHORUS.

Soil No	Locality	Rank in order of N.	Rank in order of P.	Nitrogen in Soil P.ct.	Nitrogen in Sub-soil P.ct.	Phosphorus in Soil P.ct.	Phosphorus in Subsoil P.ct.
1	Herman, M	34	72	.364	.140	.070	.057
2	Ardock, M.	35	77	.360	.189	.067	.079
3	St. John, N.D.	40	95	.358	.176	.061	.045
4	Penn, N.D.	43	93	.349	.167	.062	.079

Yield of Crops in Pots with Fertilizer.

Blank Grams	N' Grams	P Grams	NP Grams	NPK' Grams	K' Grams	Soil No.
7.4	7.4	6.6	9.4	9.	7.6	1
2.6	2.1	3.1	3.2	3.3	2.3	2
8.2	12.4	9.	12.	14.	9.	3
10.2	10.2	19.2	15.2	15.2	11.5	4
4.2	5.1	9.5	8.	9.5	5.5	5
11.	12.3	12.5	13.4	17.8	12.	6
5.5	10.2	9.6	14.8	5.6	8.2	7
2.	2.2	3.6	3.6	3.7	6.9	8
5.8	6.7	7.8	9.4	12.4	5.6	9
8.2	8.8	7.	10.2	10.2	8.8	10
4.1	4.3	4.	5.5	5.3	4.5	11
3.6	3.8	5.8	7.4	9.2	4.6	12
17.5	23.8	24.2	25.4	22.5	21.5	13
4.8	4.9	7.5	6.8	8.	4.8	14
12.	13.	15.	13.8	16.	14.5	15
3.9	5.	4.5	4.8	6.	3.4	16
6.9	8.3	8.7	10.2	10.5	8.2	
4.5	5.2	4.5	4.6	4.6	3.6	1
4.5	4.5	4.3	5.8	5.5	3.5	2
5.	5.	5.6	6.	5.8	3.	3
3.9	3.9	5.2	7.8	8.9	4.9	4

TABLE 1. (Continued)

SOILS INTERMEDIATE IN NITROGEN AND LOW IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
5	Litchfield, M.	49	74	.335	.141	.069	.058
6	Hannah, N.D.	52	81	.325	.159	.068	.059
7	De Graff, M.	55	82	.321	.210	.068	.056
8	Carlisle, M.	59	71	.314	.169	.070	.059
9	Erdahl, M.	60	69	.311	.175	.070	.069
10	Aneta, N.D.	61	92	.310	.154	.063	.057
11	Hutchinson, M.	65	90	.302	.141	.064	.042
	AVERAGE	50	81	.332	.166	.067	.060

SOILS LOW IN NITROGEN BUT HIGH IN PHOSPHORUS

1	Ada, M.	74	2	.254	.112	.124	.073
2	Arthur, N.D.	84	22	.207	.118	.080	.052
3	Maxbass, N.D.	88	20	.193	.086	.086	.084
4	Walhalla, N.D.	82	28	.219	.133	.083	.078
	AVERAGE	82	18	.218	.112	.095	.072

SOILS LOW IN NITROGEN AND INTERMEDIATE IN PHOSPHORUS

L	McVille, N.D.	68	56	.285	.116	.075	.050
2	Hunter, N.D.	69	55	.280	.114	.076	.065
3	Willow City, N.D.	71	41	.269	.152	.079	.065
4	Ellendale, N.D.	72	60	.267	.083	.073	.065
5	Erie, N.D.	73	63	.263	.131	.072	.062
6	Sauk Center, M.	75	61	.251	.210	.073	.063
7	Pelican Rapids	78	59	.229	.123	.074	.060

Yield of Crops in Pots with Fertilizer.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
.3.2	3.2	5.8	7.5	8.5	3.2	5
6.9	7.2	9.	11.5	11.	8.6	6
3.	2.5	5.	5.8	6.5	4.	7
25.7	27.8	27.	38.	39.5	26.	8
9.	9.5	9.5	14.5	14.5	6.5	9
4.4	4.2	5.1	5.4	6.	4.8	10
3.7	3.3	4.5	4.7	5.6	3.6	11
6.7	6.9	7.8	10.1	10.6	6.5	12
1.	1.2	2.2	2.8	3.2	2.1	1
3.6	4.	4.1	6.8	6.8	3.2	2
4.4	5.5	5.1	7.4	6.5	3.9	3
4.7	5.5	5.5	7.6	6.6	3.7	4
3.4	4.1	4.2	6.2	5.8	3.2	
2.8	4.	3.5	6.1	5.1	3.5	1
6.5	6.3	5.5	8.9	8.3	5.2	2
17.8	18.	22.4	23.	22.2	20.	3
3.4	3.8	5.4	5.	6.4	4.4	4
2.3	2.2	3.5	4.7	4.7	2.5	5
11.8	12.	16.7	14.	22.	11.5	6
8.	11.5	9.4	13.	21.	11.5	7

TABLE 1.(Continued)

SOILS LOW IN NITROGEN AND INTERMEDIATE IN PHOSPHORUS

Soil No	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
8	Towner,N.D.	79	67	.229	.123	.071	.058
9	Stephen,M	83	46	.218	.131	.078	.067
10	Bertha,M.	86	47	.205	.050	.079	.054
11	Sauk Center,M	93	62	.138	.064	.072	.061
	AVERAGE	77	56	.239	.118	.075	.061

SOILS LOW IN BOTH NITROGEN AND PHOSPHORUS

Soil No	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
I	Northwood,N D	70	68	.269	.145	.071	.067
2	Tolna,N D	76	83	.239	.091	.067	.040
3	Barnesville,M	77	76	.237	.114	.069	.070
4	Dünseith,N D	80	75	.224	.113	.069	.061
5	Prindeton,M	81	84	.221	.172	.067	.051
6	Brandtford,N D	85	91	.206	.095	.063	.056
7	McIntosh,M	87	85	.198	.107	.067	.056
8	Bertha,M.	89.	79	.174	.058	.069	.061
9	Danvers,Minn	90	99	.172	.118	.051	.058
10	Melrose,M	91	94	.165	.062	.061	.051
11	Appleton,M	92	96	.162	.110	.069	.069
12	Wadena,M	94	86	.137	.031	.065	.041
13	Bagley,M	95	97	.128	.036	.059	.056
14	Hensel,N D	96	89	.118	.073	.064	.076
15	Hinckley,M	97	88	.111	.038	.064	.049
16	Evansville,M	98	98	.110	.154	.058	.056

Yield of Crops in Pots with Fertilizer.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
5.3	6.4	7.3	7.4	7.6	5.2	8
3.3	4.1	6.6	4.2	4.2	3.2	9
7.8	7.5	8.2	9.3	11.5	8.8	10
14.3	16.5	14.3	16.5	17.3	13.3	11
7.6	8.4	9.4	10.2	11.8	8.1	
5.6	6.	6.8	9.	9.7	5.3	1
4.2	4.5	5.1	5.7	6.1	5.1	2
11.	13.8	18.1	31.7	36.	13.4	3
5.6	6.3	7.	8.	8.3	6.3	4
3.	5.5	3.5	5.5	7.2	2.5	5
9.	10.	11.4	13.6	13.5	11.	6
11.	13.5	20.	24.2	30.1	12.	7
8.7	7.5	9.5	9.	9.4	7.1	8
7.2	9.3	12.4	17.	14.	10.4	9
3.2	3.4	3.8	3.3	4.	3.3	10
4.1	4.4	4.8	4.5	4.5	3.5	11
6.6	7.5	6.1	6.1	7.9	6.6	12
15.2	18.	15.	19.3	17.	18.5	13
4.5	7.8	8.5	13.	9.	12.	14
9.5	13.	9.5	13.2	18.5	10.3	15
6.6	9.6	7.6	11.8	14.	7.6	16

TABLE I. (Continued)

SOILS LOW IN BOTH NITROGEN AND PHOSPHORUS.

Soil	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.ct.	Nitrogen in subsoil P. ct.	Phosphorus in Soil P.ct.	Phosphorus in Subsoil P.ct.
17	Park Rapids, M.	99	80	.100	.094	.069	.058
18	Bemidji, M.	100	100	.071	.011	..047	.045
	Average	89	87	.169	.090	.063	.057

Yield of Crops in Pots with Fertilizer.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
4.6	5.8	5.8	6.5	6.3	6.	17
11.5	14.2	10.	14.2	14.2	12.	18
7.3	8.0	9.2	11.4	12.8	8.5	19

Arranged in Groups in Order to Show the Relation of the Yield to the Composition of the Soil.

TABLE II. SUMMARY OF DATA OF 1912-13.

	Rank in order		Nitrogen		Phosphorus	
	N	P	Soil P.ct.	Sub-soil P.ct.	Soil P.ct.	Sub-soil P.ct.
22 Soils high in N & P	14	15	.418	.179	.093	.072
7 Soils high in N, int. in P	21	46	.394	.198	.077	.066
4 Soils high in N, low in P	27	77	.383	.179	.068	.065
33 Soils high in N, Average	17	29	.409	.183	.087	.070
10 Soils Int. in N, high in P	42	22	.351	.158	.085	.070
16 Soils " " " int. " "	54	48	.323	.162	.076	.064
11 Soils " " " low " "	50	81	.332	.165	.066	.059
34 Soils " " " Average	50.1	53	.331	.162	.082	.064
4 Soils low in N, high in P	82	18	.218	.112	.094	.071
11 Soils " " " int. " "	77	56	.239	.118	.074	.060
18 Soils " " " low " "	89	87	.169	.090	.063	.056
33 Soils " " " Average	84.1	68.3	.198	.102	.071	.060

Yield of crops in pots with Fertilizer.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams
8.7	10.6	12.7	16.2	16.1	10.
7.3	8.6	9.3	11.8	14.9	8.
6.2	6.9	8.0	9.8	9.4	7.1
8.1	9.7	11.4	14.4	15.0	9.2
8.3	9.8	10.2	14.4	13.6	9.1
6.9	8.3	8.7	10.2	10.5	8.2
6.7	6.9	7.8	10.1	10.6	6.5
7.1	8.2	8.7	11.0	11.1	7.8
3.4	4.0	4.2	6.1	5.8	3.2
7.6	8.4	9.4	10.2	11.8	8.1
7.3	8.9	9.2	12.0	12.8	8.5
6.9	8.1	8.7	10.6	11.6	7.7

TABLE II. (Continued)

Increase due to Fertilizer.

	N Grs.	P Grs.	NP Grs.	NPK Grs.	K Grs.
Soils high in N and P	1.9	4.	7.5	7.4	1.3
Soils high in N and Int.P	1.3	2.	4.5	7.6	.7
Soils high in N and low P	.7	1.8	3.6	3.2	.9
Average	1.6	3.3	6.3	6.9	1.1
Soils Int. in N and high P	1.5	1.9	6.1	5.3	.8
Soils Int. in N and Int. P	1.4	1.8	3.3	3.6	1.3
Soils Int. in N and low P	.2	1.1	3.4	3.9	0
Average	1.1	1.6	3.9	4.	.7
Soils low in N and high P	.6	.8	2.7	2.4	0
Soils low in N and Int. P	.8	1.8	2.6	4.2	.5
Soils low in N and low P	1.6	1.9	4.7	5.5	1.2
Average	1.2	1.8	3.7	4.7	.8

N P.ct.	P P.ct.	NP P.ct.	NPK P.ct.	K P.ct.
22	46	90	85	15
18	28	62	104	10
11	29	58	52	15
20	40	78	85	14
18	23	74	64	9
20	26	48	52	4
3	16	51	58	0
16	23	55	56	10
18	20	79	71	0
11	24	34	57	6
22	26	64	75	16
17	26	54	68	12

TABLE III. DATA ON WORK OF YEAR 1913-1914.

SOILS HIGH IN BOTH NITROGEN AND PHOSPHORUS

Soil No.	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.ct.	Nitrogen in Sub-soil P.ct.	Phosphorus in Soil P.ct.	Phosphorus in Sub-soil P.ct.
415	Willmar, M.	1	17	.590	.244	.099	.073
476	Thief River Falls	3	37	.504	.222	.092	.075
444	Glaston, N. D.	4	29	.501	.243	.093	.078
425	Hallock, M.	5	1	.499	.187	.120	.071
535	Lawton, N. D.	7	44	.492	.162	.091	.066
485	Reynolds, N. D.	8	41	.473	.094	.091	.088
442	Neche, N. D.	9	11	.467	.209	.100	.092
455	Grafton, N. D.	10	34	.465	.324	.092	.077
417	Murdock, M.	11	8	.452	.178	.103	..055
506	Kennedy, M.	12	16	.450	.200	.099	..093
407	Davenport, M.	14	61	.429	.331	.087	.083
481	Hatton, N. D.	15	12	.426	.290	.100	.077
443	Hamilton, N. D.	16	13	.425	.187	.100	.081
508	Stephen, M.	17	22	.423	.134	.096	.080
440	St. Thomas, M.	18	58	.422	.187	.088	.086
453	Grafton, N. D.	19	14	.421	.258	.100	.089
419	Donaldson, M.	22	28	.414	.309	.094	.078
463	Park River,	24	6	.411	.193	.107	.080
543	Edmore, N. D.	25	48	.410	.265	.090	.070
533	Holloway, M.	27	25	.408	.192	.094	.073
599	Argusville	30	38	.395	.174	.092	.070
603	Sauk Center	31	15	.394	.268	.099	.077
468	Mallory, M.	34	51	.392	.098	.089	.085
525	Garfield, M.	37	26	.389	.191	.094	.083

Arranged in order of Nitrogen content in order to show the relationship of the crop yield to the composition of the soil.

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
50	47.3	56	72.8	74	53	415
42.4	62	43	77	64.5	43.5	476
39.3	45.2	45.7	75.5	84	40	444
50.3	70.8	53.5	77	67	49	425
46	54	46.2	62.5	60.8	45.8	535
46.5	56.5	56.5	52.5	82.5	54	485
58	72	60.2	80	79	61.5	442
52	66.8	52.3	71.2	68.2	57.3	455
49	63	51.5	71.8	69.5	54.5	417
48.5	64.8	60.2	82.9	81	48	506
46.2	55	42.5	62	43.8	45	407
44.8	59.8	47.8	80.8	74.6	49.1	481
47	49.5	46.5	77	70.5	47.5	443
46.5	59	47.8	71	72	45.5	508
46	46.2	48.5	71.2	77.5	44.7	440
44.4	59.7	43.2	63.9	66.9	45.9	453
45	60	45.8	73.7	68.2	41.8	419
40	57.5	43.5	63	63	45.5	463
53.2	53.7	52.8	72.7	75.2	53.2	543
39.8	39.8	44.8	59.3	63.2	42.2	533
54	56.8	53	72.8	76.2	53.7	599
36.5	39.7	34.2	39.6	39.6	34.7	603
47	54	43.2	61.7	53	49	468
34.3	31.7	46.7	32	47.5	32	525

(TABLE III. Continued)

SOILS HIGH IN BOTH NITROGEN AND PHOSPHORUS

Soil No.	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.ct.	Nitrogen in Sub-soil P.ct.	Phosphorus in Soil P.ct.	Phosphorus in Sub-soil P.ct.
522	Pelican Rapids	38	43	.388	.150	.091	.075
494	Portland	39	47	.388	.144	.085	.069
538	Luverne, N. D.	41	54	.381	.205	.088	.068
448	Ashby, M.	42	59	.378	.205	.088	.070
571	Grand Forks	44	3	.366	.200	.109	.095
401	Neilsville	46	45	.365	.173	.091	.073
568	Ada, M.	51	4	.354	.201	.109	.099
596	McVille, N. D.	52	23	.353	.185	.095	.067
584	Barnsville	53	55	.352	.145	.083	.074
451	Cavalier, N. D.	59	20	.384	.070	.097	.063
573	Munich, N. D.	63	63	.343	.115	.086	.071
510	Warren, M.	65	7	.342	.141	.104	.086
	AVERAGE	28	30	.416	.197	.0954	.0784

SOILS HIGH IN NITROGEN AND INTERMEDIATE IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.ct.	Nitrogen in Sub-soil P.ct.	Phosphorus in Soil P.ct.	Phosphorus in Sub-soil P.ct.
455	Arvilla, N. D	2	65	.537	.222	.086	.077
554	Cottonwood, M.	6	89	.499	.173	.083	.070
456	Milton, N. D.	13	84	.430	.199	.084	.080
449	Cando, N. D.	21	104	.415	.145	.080	.066
430	Antler, N. D.	23	93	.414	.162	.082	.057
496	Cando, N. D.	26	99	.409	.139	.081	.062
491	Clifford, N. D.	28	114	.406	.026	.078	.072
465	Hannah, N. D.	29	110	.396	.147	.079	.059
461	Rock Lake, N. D.	32	125	.396	.145	.076	.069
588	Chokio, M.	33	71	.392	.196	.085	.077
493	Page, N. D.	36	86	.390	.233	.084	.075

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
53.8	29.3	28.8	58	52.5	30.8	522
51.9	68	54.5	88	85	45.2	494
46	55.8	50	62.2	62.2	47.5	538
45.5	43	51.2	68.5	71.8	45.8	448
41.2	43	41.3	60.4	59.6	41	571
22	17.3	32.3	46.3	28.3	26	401
37.8	58	44.2	62.5	62.1	51.2	568
45.2	56	55.3	71.8	69.8	50.1	596
52	51.3	61.2	69.4	67.4	41.5	584
47	63	52	61.2	73.2	49.5	451
45.7	44.6	50.5	59.8	44.5	46.9	573
64.5	72.9	66.9	72.4	71.4	63.9	518
46.1	53,5	48.7	66.8	65.8	48.5	

Yield of Crops in Pots.

73	60.5	61	66	73	66	455
36.5	42.2	44.5	59.8	63.5	41.1	554
51	46	54.5	55	58.7	35	456
54.5	74.2	59.7	67.5	78.2	67.5	449
18.9	21.5	22.5	22	22.8	18.4	430
35.9	49.7	47.2	50.3	53.8	46.8	496
39.5	52.2	39	69	72.5	39	491
26.2	59.2	35.7	63.5	70.5	30.7	465
54	54	62.5	51.5	75.2	48	461
42.2	44	54	58	58.7	55	588
32.6	48.3	37.8	62	67.5	37	493

(TABLE III, Continued)

SOILS HIGH IN NITROGEN AND INTERMEDIATE IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
460	Webster, N. D.	35	82	.391	.174	.084	.087
475	Mentor, M.	40	101	.387	.010	.081	.060
437	Aneta, N. D.	45	103	.365	.169	.080	.075
479	Evansville, M.	47	77	.364	.241	.085	.075
550	Morris, M.	48	124	.359	.182	.076	.065
534	Aneta, N. D.	50	70	.357	.129	.085	.073
457	Langdon, N. D.	55	117	.350	.013	.078	.055
482	Argusville, N.D.	56	109	.350	.152	.079	.072
432	Waverly, M.	62	68	.343	.128	.086	.056
	AVERAGE	34	95	.398	.149	.082	.069

SOILS HIGH IN NITROGEN AND LOW IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
597	Crookston, M.	20	156	.416	.041	.068	.086
435	St. John, N. D.	43	141	.377	.174	.071	.071
446	Niagara, N. D.	49	137	.358	.157	.073	.049
484	Grandin, N. D.	54	128	.352	.098	.076	.058
408	Wahpeton, N. D.	58	157	.349	.220	.068	.057
434	Rollan, N. D.	60	132	.346	.188	.075	.053
579	Barnsville, M.	61	129	.345	.103	.075	.067
498	Crookston, M.	64	147	.343	.109	.070	.066
	AVERAGE	51	141	.361	.136	.072	.063

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
60.4	76.8	62	72.5	72.3	64.2	460
36.5	42.5	42	50.5	65.8	33	475
48.7	70	54.3	72.8	80	49.5	437
35.5	52.2	41.5	62.7	66.8	40.5	479
43.	54	45.2	55.5	56.6	40.6	550
43.4	56.2	55.5	64	68	47.3	534
58	61.5	46.5	65.9	63.8	43.4	457
54.2	63.2	57	66.2	65.4		482
41	63.5	56	74.5	74.5	53.8	432
44.3	54.6	49.4	60.5	65.4	45.1	
47	57	51	49	55.8	44.9	597
57	79.5	55.7	79	50.9	63.5	435
57.2	49.2	51	72.5	87.5	55	446
34.6	74.8	41	71.2	73	39	484
38	42	37	58	64.8	40.7	408
56.8	68.6	64	80	80	62.5	434
32.8	36.2	43	62.2	70.2	36.2	579
42.5	43	45	39.5	41	41	498
45.7	56.3	48.3	63.6	65.4	47.9	

SOILS INTERMEDIATE IN NITROGEN AND HIGH IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.ct.	Nitrogen in Sub-soil P.ct.	Phosphorus in Soil P.ct.	Phosphorus in Sub-soil P.ct.
580	Hancock, M.	57	87	.340	.104	.086	.069
582	Dalton, M.	68	42	.339	.012	.091	.071
605	Beltrami, M.	69	32	.339	.066	.093	.078
441	Neche, N. D.	70	21	.338	.313	.097	.084
587	Comstock, M.	72	30	.333	.142	.093	.070
489	Mayville, N. D.	77	27	.326	.133	.094	.094
530	Fergus Falls, M.	78	31	.325	.189	.093	.081
520	Luverne, N. D.	84	53	.318	.166	.088	.084
576	Climax, M.	85	36	.317	.182	.092	.082
585	Grand Forks,	93	50	.306	.087	.089	.098
602	Dalton, M.	95	60	.304	.151	.087	.067
462	St. Vincent, M.	101	19	.294	.106	.098	.079
560	Buxton, N. D.	107	39	.285	.045	.092	.054
564	Round Prairie,	111	35	.281	.151	.092	.070
436	Auburn, M.	112	40	.280	.172	.091	.085
466	Park River,	118	33	.273	.248	.093	.068
567	Glyndon, M.	119	62	.275	.175	.097	.071
544	Alexandria, M.	126	9	.264	.180	.102	.097
	AVERAGE	91	39	.308	.146	.093	.078

SOILS INTERMEDIATE IN BOTH NITROGEN AND PHOSPHORUS

Soil No.	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.ct.	Nitrogen in Sub-soil P.ct.	Phosphorus in Soil P.ct.	Phosphorus in Sub-soil P.ct.
545	Russel, M.	66	116	.341	.161	.078	.071
410	Nassau, M.	67	85	.341	.212	.083	.092
555	Clara City, M.	73	106	.332	.119	.080	.073
411	Sharon, N. D.	74	72	.331	.115	.085	.067

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
49.5	63.5	56	71.6	61.3	52.7	580
59.5	50	60	77.8	79	53	582
31.9	39.4	38.9	45	45.5	32.3	605
60	77	63	71.5	73.3	59	441
47.3	58.6	51.3	70.7	72.2	43.8	587
42	59.5	53	76.7	73.5	45	489
29.8	38	43.2	69	66.5	32.8	530
19	20	39.7	60.5	64	25.5	520
65	73.2	63.5	87.4	67.5	66.8	576
40.5	52	41	69	72.2	46.3	585
34.2	33.9	37	27.8	48	31.3	602
51.1	63.7	56.5	67.5	67.8	50.8	462
32	48	38.6	54	54.2	33.5	560
44	60	44.5	50.9	68.5	47.6	564
50.2	58	53.7	74.5	83.7	60.7	436
14.5	34	21.3	43.5	44.8	18.5	466
39.7	52.2	42.6	67.4	69.4	43	567
37.8	43	50.5	57.7	67.7	45.7	544
41.6	51.3	47.5	63.5	65.5	43.8	
41.8	50.5	59	64.7	57.9	43	545
40.5	67.2	44.2	59	37.5	38.5	410
34	43.8	31.5	58	62.5	32.2	555
44.5	51	52	59	62.7	48	411

SOILS INTERMEDIATE IN BOTH NITROGEN AND PHOSPHORUS

Soil No.	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
469	Humboldt, M.	75	90	.329	.250	.083	.082
539	Garfield, M.	76	98	.328	.171	.081	.061
570	Glyndon, M.	79	79	.325	.162	.084	.076
464	Starkweather, M.	80	81	.323	.139	.084	.073
426	Antler, N. D.	83	91	.319	.073	.083	.059
433	Emerado, M.	87	92	.314	.127	.082	.089
458	Edinburgh, N.D.	88	80	.308	.065	.084	.060
532	Hancock, M.	91	78	.306	.177	.084	.077
594	Portland, N.D.	98	74	.300	.212	.085	.078
409	Maple Plain, M.	99	69	.297	.189	.086	.053
450	Cavalier, N. D.	100	126	.297	.132	.076	.049
427	Barton, N. D.	102	76	.293	.124	.085	.076
591	Pelican Rapids	109	94	.282	.060	.082	.062
569	Ada, M.	110	73	.282	.009	.085	.086
586	Monticello, M.	116	83	.278	.010	.084	.080
581	Helmar, M.	117	96	.276	.056	.081	.065
536	Halstad, M.	120	103	.273	.175	.080	.086
606	Rothsay, M.	122	95	.273	.137	.081	.076
551	Pipestone, M.	123	123	.271	.159	.077	.076
	AVERAGE	94	90	.305	.132	.082	.072

SOILS INTERMEDIATE IN NITROGEN AND LOW IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
406	Breckenridge, M.	71	154	.338	.106	.068	.055
412	Benson, M.	81	148	.322	.080	.070	.050
459	Churches Ferry	82	151	.320	.155	.070	.053
566	Delano, M.	86	183	.315	.303	.056	.073

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
47.7	57	44	62	63	43	469
40.3	52	46.2	40	64.5	46.2	539
61.6	59.2	62.8	64	63.3	64.3	570
67	50	54	68	80.5	54	464
55.7	72	61.7	77.2	83.5	63.5	426
44	57.5	43.5	71.5	73.8	38.9	433
47	60.2	39.5	65.2	66.2	42.8	458
40.7	50	52	61.2	65.7	44.8	532
35	55.4	39.2	80	71.2	30.2	594
30	45.2	30.2	50.7	53.2	32.2	409
36.7	40.7	39.3	71	65	39.3	450
59.5	76.5	62.5	80.5	85	59	427
42.4	56.8	46.5	75.3	68.5	44.5	591
48.3	52.4	39.4	61.8	67.5	41.8	569
45	52	56	68.7	65.5	51	586
20	20.7	29	58.8	64	28	581
46.9	66	51.8	67.2	66.8	49.8	536
38.8	37.5	46.4	49.8	60	35.5	606
39.5	43.2	43	53.5	60.7	39.1	551
43.78	52.9	46.7	63.8	65.6	44.[illegible]	
40	43	36.8	37	41.5	41	406
41.7	40.8	44	60.2	60.3	40.5	412
40.8	59.5	47	67.5	75.5	43.5	459
33.7	48.2	37.1	52.6	55.9	29.3	566

SOILS INTERMEDIATE IN NITROGEN AND LOW IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
428	Willow City, N.D.	89	131	.308	.151	.075	.079
467	Perley, M.	90	167	.306	.199	.063	.077
589	Wahpeton, N. D.	92	162	.306	.171	.065	.078
452	Hoople, N. D.	94	121	.304	.200	.077	.089
402	Moorhead, M.	96	179	.304	.073	.053	.058
574	Hanley Falls,	97	140	.302	.126	.071	.053
492	Clifford, N. D.	103	160	.289	.094	.066	.049
511	Warren, M.	104	144	.288	.144	.071	.072
524	Albany, M.	105	152	.288	.083	.069	.062
559	Sutton, N. D.	106	134	.285	.069	.074	.059
470	Freeport, M.	108	176	.284	.081	.060	.081
422	Hutchinson, M.	113	138	.279	.273	.072	.072
558	Marshall , M.	114	146	.279	.126	.070	.059
562	Hillsboro, N.D.	115	161	.278	.152	.065	.066
488	Mayville, N. D.	121	136	.273	.152	.073	.065
404	Milaca, M.	124	180	.265	.043	.056	.045
416	Atwater, M.	125	163	.264	.181	.065	.053
531	Arthur, N. D.	127	158	.259	.126	.067	.061
	AVERAGE	102	154	.293	.140	.067	.064

SOILS LOW IN NITROGEN AND HIGH IN PHOSPHORUS

Soil No.	Locality	N	P	Soil P.ct.	Sub-soil P.ct.	Soil P.ct.	Sub-soil P.ct.
447	Larimore, N. D.	129	52	.256	.085	.089	.065
438	Sharon, N. D.	131	24	.246	.190	.095	.065
552	Litchfield, M.	134	57	.243	.128	.088	.067
575	Long Lake, M.	135	5	.242	.125	.107	.083
546	Baker, M.	139	58	.236	.156	.088	.074

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
14.8	19.9	14.4	29.7	25	13.8	428
27	55	42.5	55.5	53.5	30.2	467
57.5	62.7	61.5	75	76.7	52.7	589
35.2	61	40	60.2	70.5	37	452
25.5	47.2	41.5	44.6	45.2	36.6	402
43	48.5	49.7	59	63.5	47.8	574
43.8	57	38.5	71	76.5	47.5	492
38.5	58	43	63	62.8	44.6	511
41	47	50	68	73	52	524
31.8	43	34	58.5	58.2	36.4	559
31	46	33	60	64.4	31	470
50.5	60	54	77	74.7	44.5	422
31.3	46.7	32.8	54	57.8	31.3	558
33	52	35	60	67	36	562
50.5	65.7	52.2	69.8	79	50.5	488
34.9	53	40.4	52.2	66.4	43.9	404
44.2	46.2	58.2	74.5	75.2	49.7	416
39.3	47.5	38	67.5	67.2	37.5	531
37.8	50.4	41.9	59.8	63.2	39.9	
45.5	56.5	37.2	58.8	75.7	41	447
53.5	66.5	53.5	76.2	84.5	50.5	438
34.5	45.8	41.2	52	58	36	552
40.9	51.3	35.8	57.4	50.4	36.8	575
32.5	34	41.5	59.5	66.8	34	546

(TABLE III. Continued)

SOILS LOW IN NITROGEN AND HIGH IN PHOSPHORUS

Soil No.	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
509	Argyle, M.	144	2	.223	.172	.115	.078
527	Kirkhoven, M.	145	46	.221	.191	.090	.084
601	Hillsboro, N. D.	155	49	.214	.068	.069	.068
561	Osakis, M.	157	18	.206	.048	.099	.072
514	Erskine, M.	166	10	.190	.080	.102	.068
600	Fergus Falls, M.	171	64	.173	.036	.086	.070
	AVERAGE	155	35	.223	.116	.094	.072

SOILS LOW IN NITROGEN AND INTERMEDIATE IN PHOSPHORUS

Soil No.	Locality	N	P	Nitrogen Soil	Nitrogen Sub-soil	Phosphorus Soil	Phosphorus Sub-soil
454	Wallhalla, N. D.	135	67	.256	.253	.086	.077
507	Stephen, M.	130	75	.248	.092	.085	.076
595	Beardsley, M.	132	107	.244	.118	.080	.064
592	McIntosh, M.	133	120	.244	.063	.077	.057
501	Maxbass, N. D.	136	119	.241	.131	.077	.061
413	Donnelly, M.	137	113	.450	.223	.078	.064
529	Hatton, N. D.	142	88	.225	.156	.083	.054
593	Fergus Falls	143	66	.224	.064	.086	.074
505	Kennedy, M.	146	122	.221	.144	.076	.078
414	Grove City, M.	147	118	.221	.140	.078	.049
431	Rugby, N. D.	150	111	.215	.113	.079	.063
499	Howard Lake,	152	108	.213	.126	.080	.061
557	Watertown, S. D.	156	115	..207	.110	.078	.071
483	Grandin, N. D.	170	97	.176	.150	.081	.083
549	Munich, N. D.	180	112	.135	.104	.078	.065
480	Beltrami, M.	186	100	.109	.070	.081	.078
478	Red L. Falls	163	102	.195	.090	.081	.066
	AVERAGE	143	102	.212	.126	.080	.068

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
51.3	62.5	56	56.4	67.4	58.7	509
64.5	67.5	68.8	49.5	85.8	65	527
26.5	33.9	30.4	46.4	41.7	27	601
39.5	59.5	43	40	71	42.5	561
39.9	51.7	45	47	62.7	44.3	514
32.2	50	36.7	45.6	53	39.2	600
41.9	52.7	44.5	53.5	65.2	43.2	
47.8	59.9	51.9	61.5	66.5	46.7	454
54.2	64	57	68.7	75	56.2	507
51.7	60.6	49.6	77.6	86.1	44.7	595
35	52	42.5	67.5	73.5	43	592
31.7	35.5	37.2	45.6	50.5	36.9	501
50.5	58.5	54.5	78.2	73.8	51.8	413
46.5	63.8	52.5	71.2	60.5	51.8	529
38.7	46.5	36.6	59.6	59.7	40.2	593
53	55	53.5	58.5	65	47.5	505
31	29.8	35.5	50.7	53.7	32	414
11.8	18.8	11.2	21.8	21.2	11	431
35.8	41.3	38.9	41.2	49	41.3	499
36.8	35.5	38.5	60.5	57.3	36.5	557
42	70.4	41.4	72	77	39.5	483
39.4	49.7	45.7	57.2	60.5	45.7	549
35.2	45.5	35.9	68.8	69	35.3	480
43.5	61.2	45.5	71.2	66.7	42.7	478
40.3	49.9	42.8	60.7	62.6	41.4	

(TABLE III. Continued)

SOILS LOW IN BOTH NITROGEN AND PHOSPHORUS

Soil No.	Locality	Rank in order of N	Rank in order of P	Nitrogen in Soil P.ct.	Nitrogen in Sub-soil P.ct.	Phosphorus in Soil P.ct.	Phosphorus in Sub-soil P.ct.
578	Melrose, M.	138	173	.240	.067	.061	.063
526	Arthur, N. D.	140	135	.234	.098	.073	.059
547	Grandville, N.D.	141	133	.231	.092	.074	.075
528	Delano, M.	148	149	.219	.146	.070	.083
540	Campbell, M.	149	170	.218	.119	.062	.056
601	Hillsboro, N.D.	151	153	.214	.068	.068	.068
424	Upham, N. D.	153	171	.212	.111	.062	.070
563	Sauk Center, M.	154	155	.209	.109	.068	.038
512	Mentor, M.	158	177	.203	.242	.058	.057
418	Chokio, M.	159	169	.203	.166	.063	.051
421	St. Bonifacious	160	164	.203	.112	.065	.051
477	St. Hilair, M.	161	188	.200	.063	.039	.051
565	Dassel, M.	162	168	.198	.066	.063	.052
487	Northwood, N.D.	164	178	.193	.125	.056	.060
548	Hunter, N. D.	165	130	.193	.117	.075	.069
403	Milaca, M.	168	189	.187	.114	.038	.045
523	Melrose, M.	168	150	.185	.137	.070	.067
497	Erie, N. D.	169	184	.183	.056	.052	.054
517	Red L. Falls,	172	186	.171	.119	.050	.053
502	Hensel, N. D.	173	182	.169	.081	.055	.052
598	Park River, M.	174	127	.160	.072	.076	.059
490	Erie, N. D.	175	174	.159	.184	.061	.066
541	Appleton, M.	176	145	.158	.114	.070	.066
542	Upham, N. D.	177	143	.158	.101	.071	.065
577	Ogilvie, M.	178	159	.155	.037	.066	.045
556	Hunter, N. D.	179	142	.143	.032	.071	.074

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
31.5	54.2	35.7	63.5	65	35.7	578
22	27	33.7	35.5	29.7	21.7	526
47.3	56.3	48	53	63	42	547
38	44	41.5	37.5	52.5	35.3	528
40.5	53	50	61	66.2	46	540
26.4	33.9	30.4	46.4	41.7	27	601
48	65	56	74.6	68.5	49.3	424
38.3	54.5	37.6	58	67.7	39.3	563
48.2	78.5	44.5	65	72.7	48	512
49.7	73.2	47.2	80.4	71.5	44	418
32.5	66.8	37.3	73	69	35.3	421
52.5	66.8	54.2	73.5	69.5	58.3	477
31.4	58.4	36.8	61.4	57.6	38.6	565
33.5	72.5	37	72	57	35	487
54	60	48.5	57	70	51.2	548
39.2	63	42	48	60.5	46.5	403
45.5	59	41.5	62.9	67.9	48.9	523
25.8	28.8	32.1	48.4	55.3	32.8	497
40.7	45.7	45.5	60	55.8	47.5	517
49.8	45.5	43.3	46.6	47.8	41	502
34	29.5	37.5	50.5	63.7	31.7	598
32	46	33.5	62	71	31.5	490
35.8	38	38.7	61.5	63.5	43.7	541
52.5	55	55	69.2	66.5	53	542
36.2	41.7	31.9	53	57.5	33.5	577
26	29	39.7	50.2	58	27.5	556

(TABLE III. Concluded)

SOILS LOW IN BOTH NITROGEN AND PHOSPHORUS

Soil No.	Locality	Rank in order of N	P	Nitrogen in Soil P.ct.	Sub-soil P.ct.	Phosphorus in Soil P.ct.	Sub-soil P.ct.
590	Eagle Bend, M.	181	172	.130	.001	.061	.063
513	Bemidji, M.	182	181	.127	.022	.055	.047
515	Bagley, M.	183	139	.126	.125	.072	.062
553	Princeton, M.	184	185	.114	.030	.052	.052
471	Solway, M.	185	166	.112	.043	.064	.051
405	Shevelin, M.	187	175	.103	.043	.061	.054
504	Hinckley, M.	188	187	.092	.033	.039	.039
503	Shevelin, M.	189	165	.088	.036	.065	.054
	AVERAGE	167	164	.173	.091	.062	.058

Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams	Soil No.
44	52.2	44.5	66.2	72	47.3	590
35.2	58	40	51	52	37	513
55	68	51.6	67.5	75.5	55.8	515
31	47.2	34	50.2	52.8	31.5	553
41	62	45	62.5	61	44.2	471
7.3	24.8	8.8	26	29.5	20.8	405
36.8	46.8	40.5	54.3	55.5	45.5	504
39.3	52	38.7	47.1	52	39.4	503
38.3	51.7	40.[illegible]	57.3	59.9	40.2	

TABLE IV. SUMMARY OF 1913-14 DATA

	No of Soils	Rank according to N	Rank according to P	Nitrogen Av Surface P.ct.	Nitrogen Av Sub-soil P.ct.	Phosphorus Av Surface P.ct.	Phosphorus Av Subsoil P.ct.
Soils high in N & P	36	28	30	.416	.197	.095	.078
Soils high in N and Int in P	20	34	95	.398	.149	.082	.069
Soils high in N & low in P	8	51	141	.361	.136	.072	.063
AVERAGE	64	33	64	.404	.159	.088	.073
Soils Int.in N & high in P	18	91	39	.308	.146	.093	.078
Soils Int in N & Int in P	23	94	90	.305	.132	.082	.072
Soils Int in N & low in P	22	102	154	.293	.140	.067	.064
AVERAGE	63	96	98	.302	.139	.080	.071
Soils low in N & high in P	11	155	35	.223	.116	.094	.072
Soils low in N & Int in P	17	143	102	.212	.126	.080	.068
Soils low in N & low in P	34	167	164	.173	.091	.062	.058
AVERAGE	62	157	124	.191	.104	.071	.063

Arranged in order of phosphorus content in order to show the relationship of the crop yield to the composition of the soil.

Average Yield of Crops in Pots.

Blank Grams	N Grams	P Grams	NP Grams	NPK Grams	K Grams
46.1	53.5	48.7	66.8	65.8	45.5
44.3	54.6	49	60.5	65.4	45.1
45.7	56.3	48.5	63.9	65.4	47.9
45.5	54.2	48.8	64.3	65.6	45.6
41.6	51.3	47.5	63.5	65.5	43.8
43.8	52.9	46.7	63.8	65.6	44.
37.8	50.4	41.9	59.8	63.2	39.9
41.1	51.6	45.3	62.3	64.3	42.5
41.9	52.7	44.5	53.5	65.2	43.2
40.3	49.9	42.8	60.7	62.6	41.4
38.3	51.7	40.7	57.3	59.9	40.2
39.5	51.4	42.	57.6	61.6	41.1

TABLE 1V. (Continued)

Increase due to fertilizer.

	N Grams	P Grams	NP Grams	NPK Grams	K Grams
Soils high in N and high in P.	7.4	2.6	20.7	19.7	.4
Soils high in N and Int. in P.	11.5	5.2	18.	23.4	1.2
Soils high in N and low in P.	13.3	2.7	20.9	19.9	2.6
AVERAGE	9.3	3.4	18.2	20.8	.9
Soils Int. in N and high in P.	9.9	6.	22.	24.6	2.3
Soils Int. in N and Int. in P.	9.1	2.9	20.	26.1	.1
Soils Int. in N and low in P.	12.6	4.2	22.1	25.5	2.2
AVERAGE	10.6	4.5	21.3	26.9	1.5
Soils low in N and high in P.	10.7	2.5	11.6	23.3	1.3
Soils low in N and Int. in P.	9.6	2.5	20.4	22.3	1.1
Soils low in N and low in P	13.8	2.5	19.4	22	2.3
AVERAGE	12.1	2.3	18.3	22.3	2.4

N P.ct.	P P.ct.	NP P.ct.	NPK P.ct.	K. P.ct.
16	6 .	45	43.	1.
23	13.	37	48.	2.
29	6.	46	44.	6.
20	7.	39	44	2.
24	15	53	59	6
21	7	41	60	0
33	11.1	60	68	6
26	11	52	65	4
23	6	28	56	3
24	6	51	55	3
36	7	51	58	6
31	6	46	57	6

TABLE V. YIELD OF GRAIN AND STRAW.

A. Ranked according to Nitrogen in Surface Soil

No. Soil	Nitrogen P.ct.	Yield of Grain in Grams B	N	P	NP	NPK	K
444	.501	14.5	13	20.5	30	34.5	16
425	.499	22.5	31	25.5	30	28	20.6
535	.492	17.	19.4	22.	21.5	23	17
442	.467	28.7	20	26.5	27.	33.7	24.8
443	.425	16.5	16.5	20	24.	30.	20.5
508	.423	20.7	21.2	22.8	22.5	28.7	17.7
Av.for six highest in N	.467	19.9	18.5	22.9	25.8	29.7	19.4
449	.415	22.	22.	23.	20.5	29.5	17.
419	.414	17.5	18.2	20.7	28.3	26.2	19
439	.413	20.7	18.	29.	33.	33.5	21.2
435	.377	17.	19.4	22.	21.5	23.	17.
437	.365	21.9	26.	20.5	27.7	29.	21.4
446	.358	18.	30.	22.2	32.7	34.4	23.5
Av.of six next in N	.390	19.5	20.6	22.9	27.4	29.3	19.9

Yield of Straw in Grams

B	N	P	NP	NPK	K	Soil No.
24.8	32.2	35.7	45.5	49.6	24.	444
27.8	39.8	28	47.	39	28.5	425
29	34.6	24.2	41.	37.8	28.8	535
29.3	52	37.7	53	35.3	36.7	442
20.5	33	26.5	53	40.5	27.	443
25.8	37.8	25.	48.5	43.3	27.7	508
26.2	38.2	27.9	48.	40.9	28.8	
32.5	52.2	36.7	47	48.7	39.2	449
27.5	41.8	25.1	44.9	42.	22.8	419
37.	49.7	37.2	43.2	56.2	35.2	439
40.	60.1	33.7	57.5	63.	46.5	435
26.8	44.	33.8	45.1	51.	28.1	437
39.2	39.2	28.8	39.8	53.1	21.5	446
33.8	47.8	32.6	46.3	52.3	32.2	

A. TABLE V. (Continued)

No. of Soil	Nitrogen P.ct.	B	Yield of Grain in Grams N	P	NP	NPK	K
432	.350	12.5	24.5	15.4	21.2	27.5	16.5
410	.341	13.2	18.2	17.5	20.	12.7	20.
441	.338	20.	21.2	26.7	28.5	23.5	23.
537	.337	15.	19.	15.2	23.4	21.2	20.7
587	.333	20.2	18.5	23.5	27.	25.5	18.
532	.306	12.5	24.5	15.4	21.2	27.5	16.5
Av. of six next in N	.334	15.6	21.	19.	23.6	23.	19.1
511	.288	18.6	25.2	21.	18.6	20.6	20.
591	.282	17.3	19.3	21.5	24.	20.5	21.
436	.280	19.8	18.5	24.	32.	37.	21.
536	.273	18.	22.9	23.2	28.7	25.9	22.
578	.240	14.5	22.2	18.	24.2	30.2	17.
403	.187	16.2	25.2	20.5	19.5	23.2	21.
Av. of six lowest in N	.258	17.4	22.2	24.3	24.5	29.6	20.
Av. of 24	.363	18.1	21.4	21.5	25.3	27.	19.7

Yield of Straw in Grams

B	N	P	NP	NPK	K	Soil No.
33.	38.2	26.6	42.8	45.5	22	432
27.3	49.	26.7	39.	25.	18.5	410
40.	55.8	36.3	43.	49.8	36.	441
33.7	51.	39.1	49.4	58.8	28.8	537
27.1	40.	27.8	43.7	46.7	25.8	587
28.2	25.5	36.8	40.	38.2	28.3	532
31.6	43.3	32.2	43.	44.	26.6	
19.9	32.8	22.	44.4	42.2	24.6	511
25.2	37.5	25.	51.3	48.	23.5	591
30.4	39.5	29.7	42.5	46.7	39.7	436
28.9	43.1	28.6	38.5	30.9	27.8	536
17.	32.	17.7	39.3	34.8	18.7	578
23.	37.8	21.5	28.5	37.3	25.5	403
24.1	37.1	24.1	40.8	40.0	26.6	
28.4	41.7	29.2	44.6	44.4	28.6	

TABLE V. (Continued) Yield of grain & straw.

B. Ranked according to Phosphorus in Surface Soil.

Yield of Grain in Grams

Soil No.	Phosphorus P.cent.	B.	N	P	NP	NPK	K
425	.120	22.5	31.	25.5	30.	28.	20.5
442	.100	28.7	20.	26.5	27.	33.7	24.8
443	.100	16.5	16.5	20.	24.	30.	20.5
441	.097	20.2	21.2	26.7	28.5	23.5	23.
508	.096	20.7	21.2	22.8	22.5	28.7	17.7
419	.094	17.5	18.2	20.7	28.8	26.2	19.
Av.of six highest in P	.101	21.	21.4	23.7	26.8	28.4	20.9
444	.093	14.5	13.	20.5	30.	34.5	16.
587	.093	20.2	18.5	23.5	27.	25.5	18.
436	.091	19.8	18.5	24.	32.	37.	21.
535	.091	17.	19.4	22.	21.5	23.	17.
449	.090	22.	22.	23.	20.5	29.5	17
532	.084	12.5	24.5	15.4	21.2	27.5	16.5
Av.of six next in P	.091	17.7	19.3	21.4	25.4	29.5	17.6

Yield of Straw in Grams

B	N	P	NP	NPK	K	Soil No.
27.8	39.8	28.	47.	39.	28.5	425
29.3	52.	37.7	53.	35.3	36.7	442
20.5	33.	26.5	53.	40.5	27.	443
40.	55.8	36.3	43.	49.8	36.	441
25.8	37.8	25.	48.5	43.3	27.7	508
27.5	41.8	25.1	44.9	42.	22.8	419
28.5	43.4	29.8	48.2	41.8	29.8	
24.8	32.2	25.7	45.5	49.5	24.	444
27.1	40.	27.8	43.7	46.7	25.8	587
30.4	39.5	29.7	42.5	46.7	39.7	436
29.	34.6	24.2	41.	37.8	28.8	535
32.6	52.2	36.7	47.	48.7	39.2	449
28.2	25.5	36.8	40.	38.2	28.3	532
28.7	37.3	30.2	43.3	44.6	31.	

B. TABLE V. (Continued)

Yield of Grain in Grams

Soil No.	Phosphorus per cent	B	N	P	NP	NPK	K
439	.084	20.7	18	29.	33.	33.5	21.2
410	.083	13.2	18.2	17.5	20.	12.7	20.
591	.082	17.3	19.3	21.5	24 .	20.5	21.
437	.080	21.9	26.	20.5	27.7	29.	21.4
536	.080	18.	22.9	23.2	28.7	25.9	22.
537	.076	15.	19.	15.2	23.4	21.2	20.7
Av. of six next in P	.081	17.7	20.9	21.2	26.1	23.8	21.1
435	.081	17.	19.4	22.	21.5	23.	17.
511	.071	18.6	25.2	21.	18.6	20.6	20.
446	.073	18.	30.	22.2	32.7	34.4	23.5
432	.068	12.5	24.5	15.4	21.2	27.5	16.5
578	.061	14.5	22.2	18.	24.2	30.2	17.
403	.038	16.2	25.2	20.5	19.5	23.2	21.
Av. of six lowest in P	.065	16.1	24.4	19.9	23.	26.5	19.2
Av. of 24 soils	.085	18.1	21.4	21.5	25.3	27.	19.7

Yield of Straw in Grams

B	N	P	NP	NPK	K	Soil No.
37.	49.7	37.2	43.2	56.2	35.2	439
27.3	49.	26.7	39.	25.	18.5	410
25.2	37.5	25.	51.3	48.	23.5	591
26.8	44	33.8	45.1	51.	28.1	437
28.9	43.1	28.6	38.5	30.9	27.8	536
33.7	51.	39.1	49.4	58.8	28.8	537
29.8	45.7	31.7	44.4	45.	27.	
40.	60.1	33.7	57.5	63	46.5	435
19.9	32.8	22.	44.4	42.2	24.6	571
39.2	39.2	28.8	39.8	53.1	21.5	446
33.	38.2	26.6	42.8	45.5	22.	432
17.	32.	17.7	39.3	34.8	18.7	578
23.	37.8	21.5	28.5	37.3	25.5	403
28.7	40.	25.1	42.1	46.	26.5	
28.4	41.7	29.2	44.6	44.4	28.6	

TABLE VI. ORDER OF RIPENING, FINAL NUMBER OF TILLERS AND LENGTH OF STRAW.

Soil No.	Order of ripening. B	N	P	NP	NPK	K	No. of tillers. B	N	P	NP	NPK
432	3	5	6	2	4	1	0	0	0	6	7
433	3	6	1	4	2	5	0	0	0	4	3
434	3	6	1	2	5	4	2	6	8	20	20
435	4	6	1	3	5	2	0	13	1	6	13
436	3	6	1	5	4	2	0	0	0	6	4
437	6	3	1	4	5	2	0	6	4	8	16
438	3	1	5	4	6	2	0	7	0	3	13
440	3	6	1	4	5	2	0	2	0	3	10
441	3	5	4	1	2	6	0	12	0	9	12
442	3	6	1	4	5	2	2	7	1	9	8
443	3	1	6	5	4	2	0	1	2	11	6
444	5	4	3	6	1	2	0	0	0	2	7
445	3	4	5	6	1	2	2	0	2	4	10
446	3	6	1	5	4	2	1	7	0	8	14
447	5	4	1	6	3	2	0	9	2	2	18
448	5	4	1	6	3	2	0	0	0	20	18
449	3	6	1	4	5	2	0	7	3	4	12
450	5	4	3	6	2	1	0	0	0	14	3
451	3	6	1	2	5	4	0	4	0	9	7
452	3	6	1	2	4	5	0	0	0	8	9
538	3	6	5	4	1	2	0	2	0	7	8
539	3	6	5	4	1	2	0	10	0	0	4

Length of the straw, in inches.

K	B	N	P	NP	NPK	K
0	33.	35.	32.	31.	33.	34.
0	36.	38.	33.	36.	34.	36.
1	35.	34.	35.	31.	32.	37.
2	38.	35.	40.	35.	32.	42.
2	40.	30.	41.	41.	40.	43.
0	40.	38.	41.	37.	36.	41.
0	39.	34.	40.	40.	34.	40.
0	39.	36.	40.	41.	39.	40.
0	48.	36.	43.	39.	36.	43.
0	44.	38.	39.	35.	32.	41.
0	42.	38.	39.	36.	27.	40.
0	40.	42.	37.	26.	34.	38.
0	34.	40.	43.	34.	37.	43.
0	42.	37.	37.	36.	36.	38.
0	40.	36.	40.	41.	39.	40.
0	40.	35.	40.	35.	36.	27.
0	38.	38.	40.	41.	35.	42.
0	35.	37.	36.	32.	36.	36.
0	41.	38.	40.	34.	35.	38.
0	35.	39.	35.	30.	34.	36.
0	42.	41.	39.	34.	33.	40.
0	39.	36.	40.	36.	35.	38.

TABLE VI. (Continued)

Soil No.	Order of ripening. B	N	P	NP	NPK	K	No. of tillers. B	N	P	NP	NPK
540	3	6	5	4	1	2	1	3	0	5	3
541	3	6	4	5	1	2	3	1	5	5	1
542	3	6	4	5	1	2	0	2	4	8	14
579	3	6	4	1	5	2	0	0	0	12	19
580	3	5	6	1	4	2	2	7	0	28	16
581	4	5	1	2	6	3	2	0	0	0	6
512	1	2	5	4	6	3	0	12	6	21	19
513	3	6	1	2	5	4	0	7	0	5	4
514	3	4	1	5	2	6	0	2	1	0	4
515	3	6	1	2	5	4	2	13	0	20	14
516	1	3	6	2	5	4	2	5	3	7	5
510	1	3	6	2	5	4	14	12	17	18	15
413	5	4	3	6	2	1	0	0	0	10	8
414	5	4	3	6	2	1	0	0	0	5	8
415	3	5	4	6	2	1	2	0	0	8	7
416	5	4	3	1	6	2	0	3	5	16	11
417	6	5	3	4	1	2	2	3	0	17	9
418	6	3	2	5	4	1	0	14	0	20	11
AVERAGE	3.5	4.9	3.0	3.8	3.5	2.6	2.	4.4	1.5	9.3	10.2

Length of the straw, in inches.

K	B	N	P	NP	NPK	K
0	36.	37.	39.	32.	36.	38.
0	32.	34.	35.	37.	38.	42.
0	40.	40.	39.	36.	35.	40.
0	33.	35.	34.	35.	33.	34.
2	37.	36.	39.	30.	33.	35.
1	30.	34.	38.	40.	40.	32.
9	33.	33.	33.	31.	31.	30.
0	35.	35.	38.	37.	37.	39.
0	33.	36.	32.	35.	36.	36.
3	39.	35.	40.	34.	35.	40.
0	36.	36.	35.	35.	35.	37.
8	33.	33.	34.	32.	33.	35.
0	29.	30.	32.	30.	29.	32.
0	29.	33.	31.	32.	32.	34.
0	37.	35.	36.	34.	36.	38.
0	36.	37.	34.	31.	34.	38.
1	38.	36.	37.	31.	38.	38.
0	38.	33.	38.	32.	32.	38.
.3	37.2	36.	37.4	35.2	34.7	37.8

the maturing of the plants were not included in the count.

A comparison of the yields of grain and straw on an acre basis is shown in the following table. The yields are only such as might be expected in a fairly favorable season, such as 1912.

Yields per acre calculated from Table V.

Treatment	Grain		Straw	
	Yield Bush.	Increase Bush.	Yield lbs.	Increase lbs.
O	36.2	-	4,600	-
N	42.2	6.0	6,656	2,056
P	42.9	6.7	4,720	120
K	39.4	3.2	4,608	8
NP	50.6	14.4	7,128	2,528
NPK	54.0	17.8	7,088	2,488

The yields of grain obtained in the pots, when calculated on an acre basis correspond very closely to the average yields actually obtained under field conditions as reported in the Annual Report of the Experimental Farms of the Dominion of Canada for the years 1895-1903.[1] The average yields of 12 varieties

[1]Bulletin 48, Canadian Experimental Farms, 1904.

of Barley for this period were 58.3 bushels at Indian Head and 44.6 bushels at Agassiz. These yields are very similar to the yields on fertilizer plots at the Minnesota Experiment Station[2] where plot 4 of the standard rotation shows a yield of 53.7 bushels in 1898 and 45.8 bushels in 1902.

The yield of straw likewise is unusually high, but field yields of a similar order are not exceptional as may be seen by consulting the Report of the Experiment Farms[3] for 1905, where the yield of straw reaches a maximum of 8,200 pounds per acre.

CHEMICAL COMPOSITION OF THE SOIL.

The nitrogen was determined by the Kjeldahl method and the phosphorus by fusion with sodium carbonate (1912-13) or sodium peroxide (1913-14) using

[2] Bulletin 109, Minn. Agri. Experiment Station, 1908.

[3] Page 329, Experimental Farms Report, Ottawa, 1905, Canadian Government Publication.

the volumetric modification. All determinations were made in duplicate and the percentage reported is the average of two concordant data.

From each plot both a surface sample and a sub-soil were analyzed, but the pot experiment was carried out using a different (but probably very similar)[a] sample from the surface and none from the sub-soil. Hence in the discussion reference is made to only the surface samples. While the proportion of nitrogen or phosphorus in the sub-soil does not vary directly with that in the surface soil, when these are considered individually, it will be seen from Tables I. and III. that where groups are compared the proportions of these two elements in the subsoil correspond with those in the surface soil. This is made clear in the following summary.

[a] See Page 7.

1912-13	Nitrogen Surface Soil P.ct.	Nitrogen Subsoil P.ct.
Av. content of the 3* highest in N.	.408	.183
" " " " 3 interm. in N.	.331	.162
" " " " 3 lowest in N.	.198	.102

1913-14		
Av. content of the 3 highest in N.	.404	.159
" " " " 3 interm. " "	.302	.139
" " " " 3 lowest " "	.191	.104

1912-13	Phosphorus Surface Soil P.ct.	Phosphorus Subsoil P.ct.
Av. content of the 3 highest in P	.091	.085
" " " " 3 interm. " "	.077	.064
" " " " 3 lowest " "	.066	.061

1913-14		
Av. content of the 3 highest in P	.088	.073
" " " " 3 interm. " "	.084	.072
" " " " 3 lowest " "	.071	.063

It is evident that the ranking of the groups on the basis of the composition of the subsoils corresponds to that on the basis of the surface soils. But as already pointed out the composition of the subsoils can beof little interest in the present study.

*The "3" in this column refers to 3 groups and not 3 soils.

The maximum, minimum and mean content of nitrogen and phosphorus in the soils used in the two years are shown in the following table:

	1912-13	1913-14
No. of soils	100.	189.
Highest p.ct. N. found	0.530	0.590
Lowest " " " "	0.070	0.088
Av. " " " "	0.314	0.304
Highest p.ct. P found	0.124	0.120
Lowest " " " "	0.047	0.038
Av. " " " "	0.078	0.082

It is to be seen that the soils used in the first year were very similar in composition to those used in the second.

The relations of the different groups to one another is shown in the next table, only the surface soils being considered. The nitrogen shows the greatest range, the group (one third of the soils) richest in this constituent containing 206 per cent in 1912-13, and 215 per cent in 1913-14, as much as the group (one third) lowest in this. The phosphorus content showed a much narrower range, the third of the soils of 1912-13 highest in this containing only 138 per cent and that of those of 1913-14 140 percent as much as the third lowest in phosphorus, so the range when the soils were thus compared in groups was nearly three times as great for N as for P.

It is of interest to observe that in general there was a distinct relation of the N content to the P content. Thus in 1912-13 the group highest in N contained 22 per cent more P than the corresponding group lowest in N while in 1913-14 it contained 26 per cent more.

	NITROGEN		PHOSPHORUS	
	1912-13	1913-14	1912-13	1913-14
A. Grouped in order of N content.	P.ct.	P.ct.	P.ct.	P.ct.
Av. composition of 3rd highest	.408	.404	.087	.088
" " " 3rd interm.	.331	.302	.075	.080
" " " 3rd lowest	.198	.193	.071	.071
B. Grouped in order of P content.				
Av. composition of 3rd highest	.329	.316	.091	.088
" " " 3rd interm.	.319	.320	.077	.080
" " " 3rd lowest	.295	.276	.066	.071
" " " all 3 groups	.314	.304	.078	.080

	NITROGEN		PHOSPHORUS	
	1912 -13	1913 -14	1912 -13	1913 -14
C. On basis of N content.	P.ct.	P.ct.	P.ct.	P.ct
Ratio of N in highest 3rd to that in all	1.30	1.33	1.12	1.10
" " " "lowest " " " " "	0.63	0.63	0.91	0.89
" " " "highest " " " " lowest third	2.06	2.09	1.22	1.24
D. On basis of P content.				
Ratio of P in highest 3rd to that in all	1.05	1.04	1.17	1.10
" " " "lowest " " " " "	0.94	0.91	0.85	0.89
" " " "highest " " " " lowest third	1.12	1.15	1.38	1.24

THE YIELDS ON THE UNFERTILIZED SOILS.

As a rule the untreated pot of each set gave a lower yield than any other but there are many individual exceptions. The early growth of the plants in these was slower than that of those in the pots treated with fertilizers; this slow growth was quite marked until near the time of heading, when the straw lengthened out and the plants became among the tallest of all. (Table VI.) The tillers were few in number with an average, at the end, of one to each pot compared with an average of 10 in the NPK pots. The yields of grain varied with the phosphorus and nitrogen content of the soils, which in general vary alike, but the straw was the more affected by the variations in thenitrogen content.

When the individual soils are compared there is found no regularity in the relation of the yields to either the N content, the P content, or the two together. This may be illustrated by comparing the data on the two soils, 476 and 444, both high in N and high in P with those on 542 and 515, both low in N and low in P.

Soil No.	Nitrogen P.ct.	Phosphorus P.ct.	Yield of Dry matter. Grams.
476	.504	.092	42.4
444	.501	.093	39.3
542	.158	.070	52.5
515	.126	.072	55.0

When very large groups of soils are considered there is a definite relationship. In 1913-14 the 64 soils high in N gave an average yield of 46.9 grams, the 63 soils intermediate in N 41.0 grams and the 62 soils low in N gave 39.3 grams. The 65 of the same 189 soils highest in P gave an average of 44.1 grams, the 63 intermediate in P 44.4 grams, the 64 lowest in P 38.8 grams. In smaller groups the averages fail to show any such marked regularity. Yet even where the averages of 8 to 36 soils are compared the influence of a very high N content upon the yield is to be observed, the influence of the P content being less marked. This relationship between divisions is evident from the following:

	High P. Grams	Interm. P. Grams	Low P. Grams	All Soils Grams
		Season 1912-13		
High N	8.7	7.3	6.2	8.1
Interm. N.	8.3	6.9	6.7	7.1
Low N.	3.4	7.6	7.3	6.9
All Soils	6.8*	7.3*	6.7*	7.4
		Season 1913-14		
High N	46.1	44.3	45.7	45.9
Interm. N.	41.5	43.8	37.8	41.1
Low N	41.9	40.3	38.3	39.5
All Soils	43.2	42.6	40.6	42.2

*In this and the following similar tables the mean of the high, intermediate and low is used.

In Table V. the data on the 24 soils of 1913-14 show a similar relationship.

In 1913-14, on both high-P and low-P soils, the yields on those low in N are equal to those intermediate in N, and, in general, all those divisions intermediate in P, while doing much better than those low in P, do quite as well as those high in P.

In the case of the 24 soils mentioned in Table V. the yields of neither grain nor straw show any distinct relation to either the N content or the P content when comparisons are made between the four groups of 6 soils, but when two groups of 12 are employed it is seen that the average yield of both grain and straw is higher in those with the highest N content while the 12 with the highest P content gave a higher yield of grain but not of straw than the remaining 12.

	N P.ct.	Phos. P.ct.	Grain Grams	Straw Grams	Dry Matter Grams
Av. of 6 soils highest in N	.467	.083	20.0	27.9	47.9
" " " " next " N	.390	.082	19.5	33.2	52.7
" " " " " " N	.334	.084	15.6	31.5	47.1
" " " " lowest " N	.258	.071	17.4	24.1	41.5

	N. P.ct.	Phos. P.ct.	Grain Grams	Straw Grams	Dry Matter Grams
Av.of 12 soils highest in N	.429	.082	19.7	30.6	50.3
" " 12 " lowest " N	.296	.078	16.5	27.8	44.3
Av.of 6 soils highest in P	.428	.101	21.0	28.5	49.5
" " 6 " next " P	.388	.091	17.7	28.7	46.4
" " 6 " " " P	.333	.081	17.7	29.8	47.5
" " 6 " lowest " P	.300	.073	16.1	28.7	44.8
Av.of 12 " highest " P	.408	.096	19.4	28.6	48.0
" " 12 " lowest " P	.317	.077	16.9	29.3	46.2

Thus, while in the case of individual soils neither the N content nor the P content nor the two together indicate whether a low or high yield will be obtained in pot tests without fertilizers, we find that if the averages of very large numbers of soils of similar composition are in question the yields will <u>in general</u> correspond to the chemical composition, soils high in both P and N yielding more than those markedly low in both of these constituents.

THE YIELDS WITH NITROGEN FERTILIZER.

The application of nitrate caused a somewhat more vigorous early growth, a darker color and greater breadth of leaves. In 1914 after the plants had been growing about 110 days some forty students from the College of Agriculture of the University of Minnesota carried out, under my supervision, a count of the tillers and a ranking of the plants, of each of the 189 sets of pots, according to height, width of leaf and diameter of culm. The nitrate-treated plants were taller than the unfertilized and the potash-treated plants but shorter than the plants in the pots which received phosphate, either alone or in combination. The leaves were broader and the culms stouter than those of the plants in the B, K and P-pots but not as broad as those in the NP and NPK-pots. The plants on these were the latest of all in reaching maturity. The straw was shorter than that in the pots given no fertilizer or only phosphorus or potassium. The nitrate induced increased tillering, these pots showing a final average of 4.4 tillers per pot compared with one tiller on the unfertilized.

While in the case of a considerable number of individual sets the pot treated with nitrate gave a smaller yield than the one untreated, when the plants were allowed to reach maturity there was in general a marked increase. In 1913-14 this increase is marked in each of the nine subdivisions, varying from about 15 to 30 per cent. In 1912-13 the percentage increase is much smaller, indicating that the full effect of this fertilizer is to be obtained only by allowing the crop to grow much longer than was the case in that year.

	High P Grams	Interm.P. Grams	Low P. Grams	All Soils
		Yields 1912-13		
High N	10.6	8.6	6.9	9.7
Interm. N.	9.8	8.3	6.9	8.2
Low N.	4.0	8.4	8.9	8.1
All Soils	8.1	8.4	7.6	8.7
		Increase 1912-13		
High N	1.9	1.3	0.7	1.6
Interm. N.	1.5	1.4	0.2	1.1
Low N.	0.6	0.8	1.6	1.2
All Soils	1.3	1.2	.8	1.3

	High P Grams	Interm.P. Grams	Low P. Grams	All Soils
		Yields 1913-14		
High N	53.5	54.6	56.3	54.2
Interm. N.	51.3	52.9	50.4	51.6
Low N	52.7	49.9	51.7	51.4
All Soils	52.8	52.5	52.6	52.4
		Increase 1913-14		
High N	7.4	10.3	10.6	9.7
Interm. N.	9.7	9.1	12.6	10.5
Low N.	10.8	9.6	13.4	11.9
All Soils	9.3	9.7	12.2	10.7

The N content of the soil appeared to exercise no distinct influence upon the relative increase in total dry matter caused by the fertilizer. The soils lowest in P, however, seemed in 1913-14 to show a distinctly greater increase under the influence of the nitrogen fertilizer - an unexpected result - those highest in N as well as those lowest. The addition of the N fertilizer caused the low-P soils to yield practically the same as the high-P soils similarly treated.

When the grain of the 24 sets (Table V.) is considered it will be seen that under the influence of the

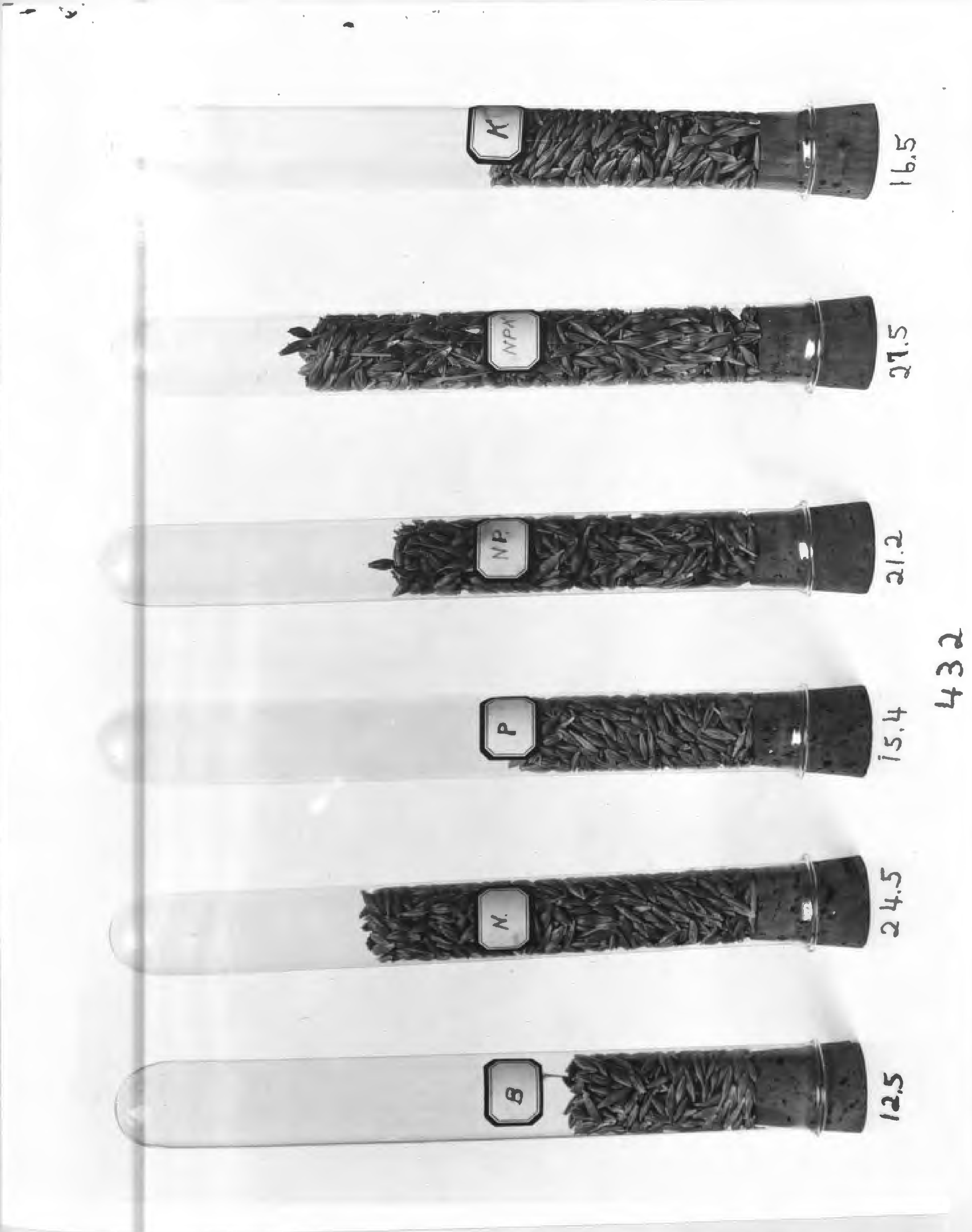

K
16.5
NPK
27.5
NP
21.2
P
15.4
432
N.
24.5
B
12.5

Photo No. 8 - THE GRAIN FROM POTCULTURES SHOWING THE INCREASE FROM THE DIFFERENT FERTILIZERS ON SOIL NO. 432 FROM WAVERLY, MINNESOTA THE NITROGEN SHOWS IN ALL CASES THE MOST MARKED EFFECT.

nitrate all the soil groups gave practically the same yields but the <u>increase</u> is much more marked in the case of the soils lowest in nitrogen.

	N. P.ct.	Yield Grams	Incr. Grams	Grain Incr. P.ct.	Grain Yield Grams	Straw Incr. Grams	Straw Incr. Grams
Av. of 6 soils highest in N.	.467	20.2	0.2	1.0	38.2	10.3	37
" " 6 " next " "	.390	22.3	2.8	14.0	47.8	14.6	44
" " 6 " " " "	.334	21.0	5.8	37.0	43.3	11.8	37
" " 6 " lowest " "	.258	22.2	4.8	28.0	37.1	13.0	54

Thus it appears that while the nitrate had as much effect on the increase of the straw on the high N soils as on the low N it had a much greater effect on the increase of grain on the latter. The final effect of this fertilizer appears to be to produce the same yields of both grain and straw on all the treated soils independent of their nitrogen content. The effect upon the grain yield should be considered in connection with the potassium fertilizer experiments detailed below.

THE YIELDS WITH PHOSPHORUS FERTILIZER.

The acid phosphate caused a very marked increase in the vigor of the early growth of the plants. This is well illustrated by Photo. No. 3. The effect of the phosphate is shown in the third (P) fourth (NP) and fifth (NPK) pots of each set. At the time of detailed comparison mentioned above the plants were taller than those which had received no phosphate and in breadth of leaf and stoutness of culm surpassed those in the B- and K-pots, but were behind those which had received nitrate either alone or in combination. They matured from 7 to 10 days earlier than all the others except those in the K-pots and except for these had the longest straw. The influence of the phosphate upon the tillering was less than that of the nitrate, the average number of tillers on the 189 pots being only 1.5 compared with 4.4 on the N-fertilized and 1.0 on the unfertilized pots. Comparing the pots of a single series the yield on the fertilized pot will be found less than that on the unfertilized even more frequently than was the case in those treated with nitrate. However, when the averages of groups are compared the P-pots show an increase in all comparisons. In the case of the 1913-14 data where the state of maturity was more advanced this increase is more marked, but by no means to the same extent as with the N-pots. The effect of the P upon the increase of dry matter is more marked in the early than in the later stages of growth of the plant. This is shown in Photo No. 3 where the plants in the P-pots are as large as those in the NP- and NPK-pots and very much larger than those in the N-pots. Yet at full maturity the yields of the former are far below those of any of the other three mentioned. The data from 1912-13 are especially interesting in this case. Here in every division the P-pots show a slightly greater increase than the N-pots while in the 1913-14 data the reverse is the case. The relative stages of maturity in the two cases are shown by photos No. 4 and 5.

Influence of stage of maturity upon the relative effect of phosphate and nitrate fertilizers.

	1912-13 Immature plants Excess in favor of phosphate.	1913-14 Mature plants. Excess in favor of nitrate.
	Grams	Grams
Soils high in N, High in P	2.1	4.8
" " " " interm. in P	0.7	5.6
" " " " low in P	1.1	7.8
Average	1.7	5.4
Soils Interm. in N, high in P	0.4	3.8
" " " " interm." "	0.4	6.2
" " " " low " "	0.9	8.5
Average	0.5	6.3
Soils low in N, high in P	0.2	8.2
" " " " interm. in P.	1.0	7.1
" " " " low in P	0.3	11.0
Average	0.6	9.4

The increase due to the phosphate in 1913-14 ranges from 5 to 15 per cent for the different divisions. Neither the phosphorus nor the nitrogen content of the soil appears to have exercised any influence on the increase induced by the phosphate.

	High P Grams	Interm. P. Grams	Low P. Grams	All Soils Grams
		Yield 1912-13		
High N	12.7	9.3	8.0	11.4
Interm. N	10.2	8.7	7.8	8.7
Low N	4.2	9.4	9.2	8.7
All Soils	9.0	9.1	8.3	9.6
		Increase 1912-13		
High N	4.0	2.0	1.8	3.3
Interm. N	1.9	1.8	1.1	1.6
Low N	0.8	1.8	1.9	1.8
All Soils	1.9	1.9	1.6	2.2
		Yield 1913-14		
High N	48.7	49.0	48.5	48.8
Interm. N	47.5	46.7	41.9	45.3
Low N	44.5	42.8	40.7	42.0
All Soils	46.9	46.2	43.7	45.1
		Increase 1913-14		
High N	2.6	4.7	2.8	3.3
Interm. N.	5.9	2.9	4.1	4.2
Low N.	2.6	2.5	2.4	2.5
All Soils	3.7	3.4	3.1	3.3

Considering the grain from the 24 soils in 1913-14 (Table V.) there is an increase in the case of almost every soil. As with the nitrate there seems here also a slightly greater increase in the case of the low nitrogen soils, the yield on the fertilized pots being similar while those on the unfertilized were not. When the soils are arranged according to their phosphorus content the results are similar. The yield of straw in the case of the 24 soils shows no effect from the fertilizer.

				Grain			Straw	
	Nit. Pct.	Phos. Pct.	Yield Grs.	Incr. Grs.	Incr. Pct.	Yield Grs.	Incr. Grs.	Incr. Pct.
Av. of 6 soils highest in N	.467	.083	22.9	2.9	15	27.9	0.0	0
" " " " next " N	.390	.082	22.9	3.4	17	32.6	0.6	2
" " " " " " N	.334	.084	19.0	3.4	22	32.2	0.7	2
" " " " " " N	.258	.070	21.4	4.0	23	24.1	0.0	0
Av. of 6 soils highest in P	.428	.101	23.7	2.7	13	29.8	1.3	4
" " " " next " P	.388	.091	21.4	3.7	21	30.2	1.5	5
" " " " " " P	.333	.081	21.2	3.5	20	31.7	1.9	6
" " " " lowest " P	.300	.073	19.9	3.8	24	25.1	3.6	14
" " 24 "	.363	.0840	21.6	2.8	19	29.2	0.3	1

The average yield of grain on the 24 pots with phosphate was 21.5 grams against 21.4 grams with nitrate, a grain of 3.4 and 3.3 grams respectively, while that of the straw was 29.5 and 41.6 grams respectively, gains of 0.7 and 12.8 grams.

Thus the phosphate is seen to have exerted as great an effect as the nitrate on the increase of grain and practically none at all on the straw. Accordingly we must conclude that when nitrate and phosphate were added separately the latter caused an increase in grain and none in the straw while the former increased the yield of straw markedly and the grain only to the same degree as the latter. The final effect of the phosphate seems to be to produce much the same increase, rather than the same yield, independent of the composition of the soil.

In the case of additions of only phosphate the chemical analyses do not give any evidence as to what increases in either dry matter or grain may be expected. That is to say there is practically no accord between the pot experiments and the chemical analyses as indicators of a response to phosphate fertilizers when applied alone.


K
21.2
NPK
33.5
NP
33.
4.39
P
29.
N.
18.
B
20.7

Photo 9 - THE GRAIN FROM POTCULTURES SHOWING THE INCREASE FROM THE DIFFERENT FERTILIZERS ON SOIL NO. 439 FROM BATHGATE, N. D. THIS POTCULTURE SHOWS A MARKED GAIN BY THE USE OF ACID PHOSPHATE.

THE YIELDS WITH POTASSIUM FERTILIZER.

Sulphate of potash caused very little effect during the early stages of crop growth. Photos. No. 3, 4 and 5 make this apparent. The yields at the end of about 100 days growth in 1912-13 bring this out, the increases caused by potassium sulphate being even less than that induced by the nitrate. In the case of the 1913-14 work, where the plants were allowed to reach full maturity, only a very slight increase in total crop, in some divisions it being quite negligible, was to be observed. Unlike the plants in the N-pots they showed no rapid gain in the increase in total weight during the latter portion of the growing season. The average percentage gain in the crop was highest where it was not grown to maturity, giving 13.4 percent more than the unfertilized pot; while the crop grown to maturity gave only 3.8 percent increase in yield.

These results indicate that the potassium shows relatively more gain in total weight when the crop is harvested before maturity than when it is left to mature. Here much more frequently than with either the P- or the N-pots the yield was less on the fertilized than on the corresponding unfertilized soil.

	High P. Grams	Interm.P. Grams	Low P. Grams	All Soils Grams
		Yield 1912-13		
High N	10.0	8.0	7.1	9.2
Interm. N	9.1	8.2	6.5	7.8
Low N	3.2	8.1	8.5	7.7
All Soils	7.4	8.1	7.4	8.2
		Increase 1912-13		
High N	1.3	0.7	0.9	1.1
Interm. N	0.8	1.3	-0.2	0.7
Low N	-0.2	0.5	1.2	0.8
All Soils	.8	.8	,6	.9

Yield 1913-14

	High P. Grams	Interm.P. Grams	Low P. Grams	AllSoils Grams
High N	45.5	45.1	47.9	45.6
Interm. N	43.8	44.0	39.9	42.5
Low N	43.2	41.4	40.2	41.1
All Soils	44.5	45.2	42.7	43.8

Increase 1913-14

High N	.6	0.8	2.2	0.1
Interm. N	2.2	0.2	2.1	1.4
Low N	1.3	1.1	1.9	1.6
All Soils	1.0	.7	2.1	1.0

At the end of 110 days in 1913-14 the height, breadth of leaf and stoutness of culm were found less affected than by any other fertilizer, the influence on each being very slight. Contrary to expectation the plants in general matured earliest, earlier even than those receiving acid phosphate only, and the straw was stronger, longer and stiffer than with any other treatment. The tillering was found unaffected, the average number being 0.8 against 1.0 on the unfertilized soils. The increase in yield of total dry matter does not seem associated with either a high or a low nitrogen or phosphorus content, although the division high in both N and P shows a smaller increase than the division low in both.

The average yield of grain on the 24 pots was 19.7 grams, a gain of 1.5 grams, compared with 3.4 and 3.3 from phosphate and nitrate, respectively. The average yield of straw on the same pots was 28.8 grams, just the same as on the unfertilized ones.

	GRAIN			STRAW		
	Yield Grs.	Incr. Grs.	Incr. P.ct.	Yield Grs.	Incr. Grs.	Incr. P.ct.
Av. of 6 soils highest in N	19.4	-0.5	-3	28.8	0.9	3
" " " " next " "	19.9	0.4	2	32.2	-1.0	-3
" " " " " " "	19.1	3.5	22	26.6	-4.9	-16
" " " " lowest " "	20.3	2.9	17	26.6	2.5	8
" " 24 "	19.7	1.5	9	28.8	0.0	0

The effect on the yield of grain is slight on the soils highest in nitrogen but distinct on those lower. This may possibly be due to a greater amount of potash liberated in the former where the content of organic matter also is higher.

As both the nitrate and the potash fertilizer are able to exert a distinct effect upon the yield of grain in the low nitrogen soils and little or no effect on the high nitrogen soils it appears quite probable that the action of sodium nitrate may be resolved into that of its nitrogen which increases the yield of straw only and that of its sodium which liberates potassium from the soil and increases the yield of grain in low N soils. The potassium fertilizer exerts no distinct effect upon the yield of straw, the increase in total dry matter evidently being due entirely to the increase in the wieght of grain. It is very evident that in trials of potash on cereals the determination of the yield of grain is most important.

As only a very few determinations of the potassium in the soils were made we have no basis for a comparison of these with the results of the pot experiments with sulphate of potash.

16.5 25.9 19.6 36.2 30.2 26.5

435

Photo 10 - THE GRAIN FROM A POTCULTURE SHOWING THE INCREASE FROM THE DIFFERENT FERTILIZERS ON A SOIL FROM ST. JOHN, N. D. No. 435. THIS POTCULTURE SHOWS A SLIGHT GAIN FROM THE USE OF POTASSIUM FERTILIZER.

It is of interest to observe that it was the low-N soils, and accordingly those of coarse texture, which showed the chief response to the potassium fertilizer - which is fully in accord with the results of European field experiments.

THE YIELDS WITH A FERTILIZER CONTAINING BOTH NITROGEN AND PHOSPHORUS

The effects of both fertilizers were to be recognized, including the early rapid growth due to the phosphorus (Photos Nos. 3, 4 and 5). At the time of the examination of the pots by the college students already referred to the the plants were taller, the leaves broader and the culms stouter than in any of the other pots except those receiving the complete fertilizer. The influence on tillering was marked, the average number on the 189 pots being 9.3, an increase of 8.3 over the unfertilized, compared with 0.5 due to the phosphate alone and 3.4 to the nitrate alone. Thus, the increase in the number of tillers was more than 100 per cent greater than was to have been expected from the effect of the two individual fertilizers. The plants matured later, being exceeded in length of growing-season only by the plants fertilized with nitrate only and at that time having shorter straw than any except those with the complete fertilizer. As the growing season was prolonged to a greater extent in the N-pots than it was shortened in the P-pots the effect of the two upon the "earliness" appears to be simply the mean of the effects of the individual fertilizers when used separately. The effect upon the length of the straw bears a similar relation, the plants in the N-pots being shorter than, and those in the P-pots similar to, those in the check pots. The shortening of the straw shown in the NP-pots was accordingly to be expected.

The effect upon the yield of dry matter is in most cases very marked. This is well illustrated by the fact that among the 189 sets in 1913-14 on only five

(406, 527, 528, 539 and 602) did the fertilizer fail to show a distinct benefit. Accordingly even every small division shows a marked increase. The total increase in dry matter in 1913-14 was much greater on account of the longer period of growth but the proportionate increase was much the same in 1912-13, indicating that this fertilizer mixture has the same relative effect upon the production of plant material in the early as in the later period of the barley's growth.

	High P. Grams	Interm.P. Grams	Low P. Grams	All Soils Grams
		Yields 1912-13		
High N	16.2	11.8	9.8	14.4
Interm. N	14.4	10.2	10.1	11.0
Low N	6.1	10.2	12.0	10.6
All Soils	12.2	10.7	10.6	12.
		Increase 1912-13		
High N	7.5	4.5	3.6	6.3
Interm. N	6.1	3.3	3.4	3.9
Low N	2.7	2.6	4.7	3.7
All Soils	5.4	3.5	3.9	4.6

	High P Grams	Interm.P. Grams	Low P. Grams	All Soils Grams
		Yields 1913-14		
High N	66.8	60.5	63.9	64.3
Interm. N	63.5	63.8	59.8	62.3
Low N	53.5	60.7	57.3	57.6
All Soils	61.3	63.9	57.8	61.7
		Increase 1913-14		
High N	20.7	16.2	18.2	18.8
Interm. N	21.9	20.0	22.0	21.2
Low N	11.6	20.4	19.0	18.1
All Soils	17.8	18.9	19.7	19.4

The phosphorus content of the soils appeared to exert no influence upon either the yield or the increase of dry matter. Their nitrogen content seems not to affect the increase, with the result that the high N soils gave with this fertilizer the highest yields of dry matter.

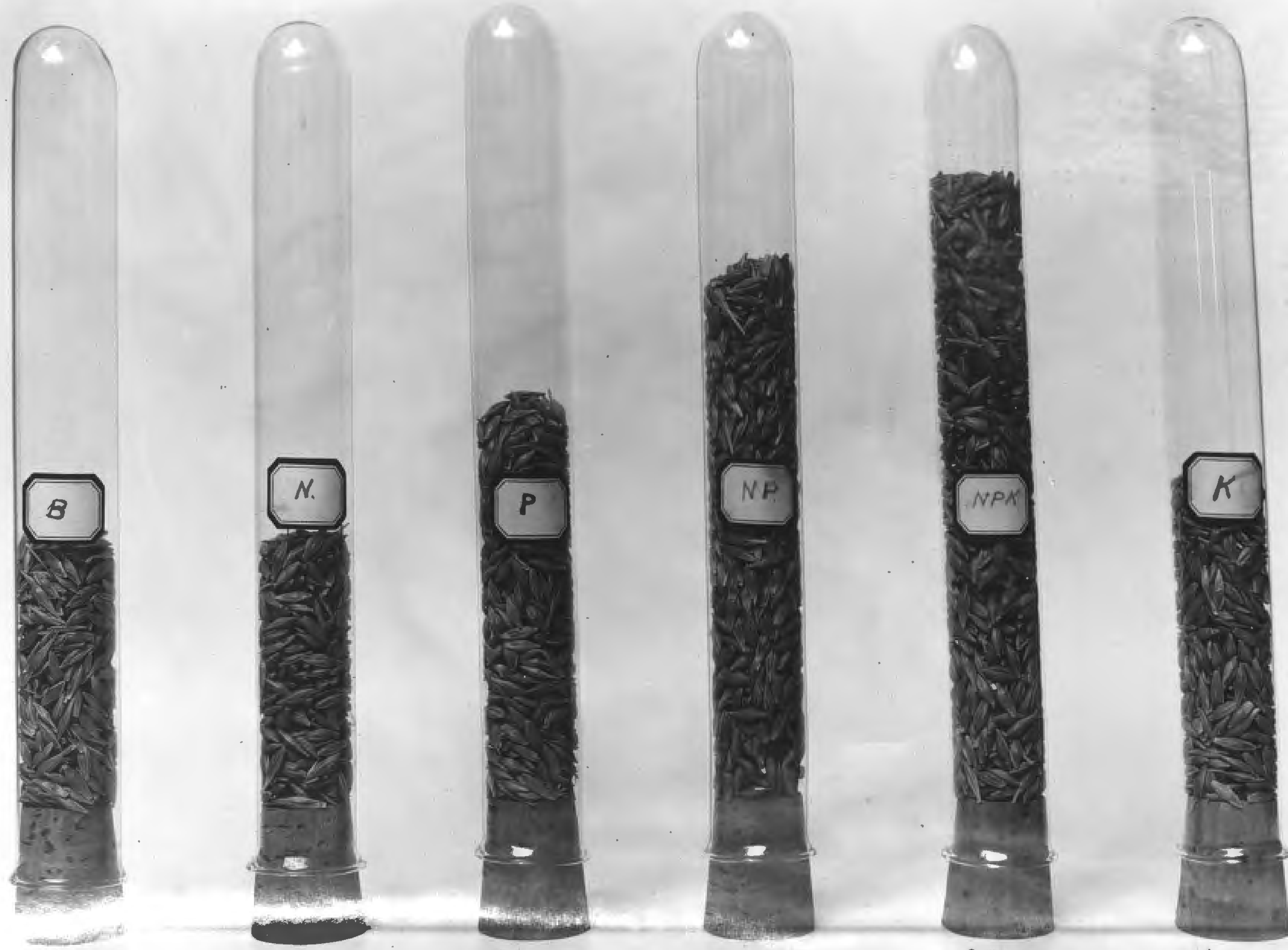
Conclusions as to the effect upon the grain and straw separately have to be based upon the data from the 24 soils reported in Table V. The yield of grain was 25.3 and of straw 45.6 grams compared with 18.1

and 28.8 grams on the unfertilized soils. The increase due to the fertilizer is considerably greater in the case of the straw than in that of grain, viz. 54 per cent against 46 for nitrate alone and 3 for phosphorus alone, while on the grain it is 40 against about 18 for nitrate alone and 19 for phosphate alone. The combined effect of the two fertilizers is, accordingly, not distinctly greater on the increase of either straw or grain than was to be expected from the effects of the two used separately.

	GRAIN			STRAW		
	Yield Grams	Incr. Grs.	Incr. P.ct.	Yield Grams	Incr. Grs.	Incr. P.ct.
Av. of 6 soils highest in N	25.8	5.8	29	48.0	20.1	72
" " " " next " "	27.4	7.9	40	46.3	13.1	39
" " " " " " "	23.6	8.0	51	43.0	11.5	37
" " " " lowest " "	24.5	7.1	41	40.8	16.7	69
" " 24 "	25.3	7.2	40	44.5	15.3	54
Av. of 6 soils highest in P	26.8	5.8	28	48.2	19.7	69
" " " " next " "	25.4	7.7	42	43.3	14.6	51
" " " " " " "	26.1	8.4	47	44.4	14.6	49
" " " " lowest " "	23.1	6.9	42	42.1	13.4	47

The N-content of the soil shows no distinct effect upon the relative increase in yields caused by the fertilizer but the higher yield of straw on the high -N soils is shown even here.

There is a marked lack of accord between the fertilizer response indicated by the chemical analysis and that shown by the pot experiments. Thus in the 1913-14 data it will be seen that the average increase in dry matter is 20.7 grams on the 36 soils highest in both N and P compared with 19.4 grams on the 34 soils lowest in both N and P. The average yields, however, are 66.8 and 57.3 grams respectively, thus making the increase 45 and 51 per cent. Thus, whatever factors may have caused the lower yield of the low-N, low-P soils appear to continue equally operative even after the addition of NP fertilizer. If the chemical analyses indicated in accord with the pot tests the low-N, low-P soils should have shown a distinctly greater effect from the fertilizer than did the high-N, high-P soils.



14.5 13. 20.5 30. 34.5 16.

444

Photo No. 11 - THE GRAIN FROM A POTCULTURE SHOWING AN INCREASE FROM THE DIFFERENT FERTILIZERS ON SOIL NO. 444 FROM GLASSTON, N. D. THIS POTCULTURE IS A TYPICAL EXAMPLE OF THE INCREASE SHOWN BY THE USE OF N AND P AND ALSO BY A COMPLETE FERTILIZER.

THE YIELDS WITH THE COMPLETE FERTILIZER

The appearance of the plants in the NPK-pots did not differ markedly at any period of their growth from those in the NP-pots. Any time after they were two months old, however, a detailed examination would show that they were slightly more thrifty. Thus in the examination at the end of about 110 days it was found that they were on the average taller, wider in leaf, stouter in culm and bore more tillers than any of the other plants. All of these effects were to be expected from the individual action of the three fertilizers as shown by N, P and K pots. For instance the average number of tillers finally persisting was 10.2 against 9.3 in the NP, 4.4 in the N, 1.5 in the P, 0.8 in the K and 1.0 in the B (check) pots. The effect of the combined fertilizers exceeded in this case the sum of their individual effects when applied separately.

The plants matured earlier than those in the NP-pots, evidently due to the action of potassium - a rather unexpected outcome. The plants were shortest of all at maturity. The yields of dry matter in both years were the highest of all, slightly higher than those on the NP-pots. The increase due to the potassium is more marked in the second year. This is shown in the last portion of the following table. By comparing this with the last portion of the table dealing with the effect of the nitrate it will be seen that the effect of the potash upon the increase in dry matter when applied along with nitrate and phosphate is distinctly greater than when applied alone.

	High P Grams	Interm.P. Grams	Low P. Grams	All Soils Grams
		Yields 1912-13		
High N	16.1	14.9	9.4	14.4
Interm. N	13.6	10.5	10.6	11.0
Low N	5.8	11.8	12.8	10.6
All Soils	12.2	12.4	10.8	12.
		Increase 1912-13		
High N	7.4	7.6	3.2	6.3
Interm. N	5.3	3.6	3.9	4.0
Low N	2.4	4.2	5.5	4.7
All Soils	5.	5.1	4.2	5.
		Yields 1913-14		
High N	65.8	65.4	65.4	65.6
Interm. N	66.5	65.6	63.2	64.3
Low N	65.2	62.6	59.9	61.6
All Soils	65.8	64.5	62.8	63.8
		Increase 1913-14		
High N	19.7	21.1	19.7	20.1
Interm. N	23.9	21.8	25.4	23.2
Low N	23.3	22.3	21.6	22.1
All Soils	22.3	21.7	22.2	21.8
		Excess of Increase over that with N and P only.		
High N	-1.0	4.9	1.5	1.3
Interm. N	2.0	1.8	3.4	2.0
Low N	11.7	1.9	2.6	4.0
All Soils	4.1	2.9	2.5	2.4

The phosphate content exerts no distinct influence upon either the final yield or the increase of the dry matter. The nitrogen content however, here as elsewhere affects the yield. Also the effect of the potash fertilizer appears possibly a little more beneficial on the soils lowest in nitrogen.

The influence of the potash, when added to the nitrate and phosphate, is, on the whole, distinctly favorable upon the yield of grain but without effect upon that of the straw. The data from the 24 soils of 1913-14 are presented below in the form of a comparison with those from the NP treatment.

Increase in yield caused by adding potash to soils already treated with phosphate and nitrate.

	GRAIN Increase		STRAW Increase	
	Grams	P.ct.	Grams.	P.ct.
Av. of 6 soils highest in N	3.9	19	-5.5	-20
" " " " next " "	1.9	10	6.0	18
" " " " " " "	-0.9	- 6	1.0	3
" " " " lowest " "	1.7	10	0.8	3
Av. of 24 soils	1.6	8	0.6	1

	Grain Increase		Straw Increase	
	Grams	P.ct.	Grams	P.ct.
Av. of 6 soils highest in P	-1.6	-6.	-6.4	-11.
" " " " next " "	4.1	13.	1.3	3.
" " " " " " "	-2.3	-11.	.6	2.
" " " " lowest " "	3.5	15.2	3.9	9.
" " 24 "	1.7	6.7	-1.2	- .4

As in the latter the effect on the straw is entirely negligible, while the grain shows an average increase of 8 against 9 percent with the NP fertilizer. However, when both P and N fertilizers are employed at the same time the effect of the potash does not seem at all related to the nitrogen content of the soil. This may be explained on the assumption that the sodium of the sodium nitrate in the NP-pots releases sufficient potash from the soil to prevent the potash fertilizer, when added to this, from showing the characteristic effect on the low'n soils that it does when used alone.

As in the case of the data from the K-pots there is here no opportunity to compare the indications of potassium response with that indicated by chemical analysis.

The excess in yield of dry matter with the complete fertilizer over each of the other fertilizers was as follows:

Fertilizer	Soils high in N Grs.	Soils Intermediate in N Grams	Soils low in N Grs.
N	11.4	12.7	10.2
P	16.8	19.0	19.6
NP	1.3	2.0	4.0
K	20.0	21.8	20.5

SUMMARY AND CONCLUSIONS.

1. 100 soil samples in 1912-13 and 189 in 1913-14 were analyzed for nitrogen and phosphorus and pot tests made with each, using nitrogen, phosphorus and potassium fertilizers, both alone, all three in combination, and also nitrogen and phosphorus to-

gether. In the first year oats, wheat and barley were used as test plants, the crops being harvested and weighed before they formed seed, but in the second year barley only was employed and the plants were allowed to ripen before being harvested. In the case of 24 sets of these latter the grain and straw were separated and weighed, while with the other 165 sets only the combined weight of straw and grain from each pot was determined.

2. The nitrogen and phosphorus both showed a wide range. The group of soils (one-third of all) highest in nitrogen averaged over 100 per cent more of this element and over 20 per cent more phosphorus than the group (one-third) lowest in nitrogen. The range in phosphorus was in general much less, the group richest in this element averaging only about 40 per cent more than the group poorest in it. The groups of soil relatively rich or poor in nitrogen are also richer or poorer in phosphorus.

3. In the case of the unfertilized soils when individual soils are compared the yields show no relation to the content of either N or P or the two together, but when very large groups are compared definite relationships are discernible. The group highest in N gave heavier yields of both grain and straw than the group lowest in N, while the group highest in P gave a heavier yield of grain, but not of straw, than the group lowest in P.

4. All the fertilizer treatments resulted, in general, in an increase in yield, the effect of the nitrogen being to increase both grain and straw, of the potassium to increase the grain only and of the phosphorus to increase the grain distinctly and the straw but little, if any. In the case of various individual sets of pots one of the fertilized pots might be found to give a lower yield than the unfertilized. This was especially common in the case of those receiving only potassium or phosphorus

fertilizer. When the yields of total dry matter are compared it is found that in all the subdivisions, on the basis of composition, the N P K fertilizer caused the greatest increase, the NP the next, N the next and K the least.

5. The relation of the increase in yield induced by a fertilizer to the composition of the soil has been carefully examined. Both the nitrate alone and the potash salt alone caused a greater increase in grain on the low-N than on the high-N soils, but when used in combination with phosphate this relation to the N-content of the soil was not to be observed. With all the fertilizers the increase in straw seemed independent of the composition of the soil. The phosphorus content of the soil seems to not influence the increase caused by a phosphate either alone or in combination with nitrate and a potash salt.

6. A comparison of the data from the two season's work makes it evident that much more satisfactory results are to be obtained by allowing the plants to

reach full maturity and then weighing the grain and straw separately. The relative effect of the phosphorus fertilizer both alone or in combination was much more marked in the early than in the later stages of growth, while that of the nitrate is the opposite.

7. The yields obtained in the pots, correspond, when calculated to an acre basis, to those actually obtained under field conditions.